SOLOMON RIVER BASIN TOTAL MAXIMUM DAILY LOAD

Water Body/Assessment Unit: Waconda Lake and the Waconda Lake Basin including the Lower North Fork Solomon River, Lower South Fork Solomon River, Oak Creek, Kill Creek (Bloomington), Covert Creek, Twin Creek, Carr Creek, Beaver Creek (Gaylord), and Deer Creek (Kirwin)
Water Quality Impairment: Sulfate

1. INTRODUCTION AND PROBLEM IDENTIFICATION

Subbasin: Lower North Fork Solomon, Lower South Fork Solomon, Solomon River

Counties: Jewell, Mitchell, Norton, Osborne, Phillips, Rooks, and Smith

HUC 8: 10260012 **HUC 11** (14)**: 010** (010, 020, 030, 040, 050, 060, 070) (Figure 1)
020 (010, 020, 030, 040, 050, 060, 070)
030 (010, 020, 030, 040, 050, 060, 070, 080, 090, 100)
040 (010, 020, 030, 040, 050, 060, 070, 080, 090)

10260014 **HUC 11** (14)**: 010** (010, 020, 030, 040, 050, 060)
020 (010, 020, 030, 040, 050, 060, 070)
030 (010, 020, 030, 040, 050, 060, 070)
040 (010, 020, 030, 040, 050, 060)

10260015 **HUC 11** (14)**: 010** (010, 020, 030)

Ecoregion: Central Great Plains, Rolling Plains and Breaks (27b)

Drainage Area: Approximately 2,490 square miles.

<u>Waconda Lake</u>

Conservation Pool: Area = 9,784 acres
Watershed Area: Lake Surface Area = 163:1
Maximum Depth = 14.0 meters (45.9 feet)
Mean Depth = 5.7 meters (19 feet)
Retention Time = 0.85 years (10 months)

Designated Uses: Primary and Secondary Contact Recreation; Expected Aquatic Life Support; Drinking Water; Food Procurement; Groundwater; Industrial Water Supply; Irrigation

Authority: Federal (U.S. Bureau of Reclamation) and State (Kansas Dept. of Wildlife and Parks)

2002 303(d) Listing: Solomon River Basin Lakes

Waconda Lake Basin

Main Stem Segment: WQLS: (5), 7, 9, 15, 21, & 22 (Lower North Fork Solomon River) and 3, 4, 5, 6, 7, 8, 9, 10, & 798 (Lower South Fork Solomon River) starting at Waconda Lake and traveling upstream to the Kirwin Lake dam and the Webster Lake dam.

Main Stem Segments with Tributaries by HUC 8 and Watershed/Station Number:

HUC 8: 10260012

Waconda Lake (018001)

Walnut Cr (26)
Granite Cr (24)
N. Fk. Solomon R (5)
S. Fk Solomon R (1)
S. Fk Solomon R (2)

Oak Creek (544)

Oak Cr (2)	Little Oak Cr (3)
Oak Cr (4)	Buck Cr (43)
	E. Oak Cr (40)
	W. Oak Cr (39)

Lower N Fork Solomon R. (14)

N.F. Solomon R (7)	Lindley Cr (45)		
	Lawrence Cr (44)		
	Dry Cr (42)		
	Spring Cr (8)		
N.F. Solomon R (9)			
N.F. Solomon R (15)	Cedar Cr (16)	East Cedar Cr (17)	
	Cedar Cr (18)	Middle Cedar Cr (19)	E. Middle Cedar Cr (37)
			W. Middle Cedar Cr (9019)
		West Cedar Cr (20)	
N.F. Solomon R (21)	Glen Rock Cr (41)		
	Medicine Cr (33)		
N.F. Solomon R (22)			

Beaver Creek (Gaylord) (670)

Beaver Cr (10)	E. Branch Beaver Cr (11)	
	Middle Beaver Cr (12)	W. Beaver Cr (14)
	Middle Beaver Cr (13)	

Deer Creek (Kirwin) (721)

Deer Cr (23)	Plum Cr (24)
Deer Cr (25)	Big Cr (26)
Deer Cr (27)	Spring Cr (28)
Deer Cr (29)	Plotner Cr (30)
Deer Cr (31)	Broughton Cr (34)
	Starvation Cr (38)

HUC 8: 10260014

Carr Creek (669)

Carr Cr (21)

Twin Creek (668)

Twin Cr (20)	E. Twin Cr (29)

Lower S. Fk. Solomon River (542, 543)

S. Fk. Solomon R (3)	
S. Fk. Solomon R (4)	
S. Fk. Solomon R (5)	Medicine Cr (17)
S. Fk. Solomon R (6)	Crooked Cr (27)
	Lucky Cr (26)
	Medicine Cr (16)
S. Fk. Solomon R (7)	Jim Cr (25)
	Elm Cr (15)
S. Fk. Solomon R (8)	Robbers Roost Cr (24)
	Dibble Cr (363)
	Boxelder Cr (14)
S. Fk. Solomon R (9)	Cocklebur Cr (23)
	Ash Cr (22)
	Lost Cr (13)
S. Fk. Solomon R (10)	Sand Cr (395)
S. Fk. Solomon R (798)	

Covert Creek (666)

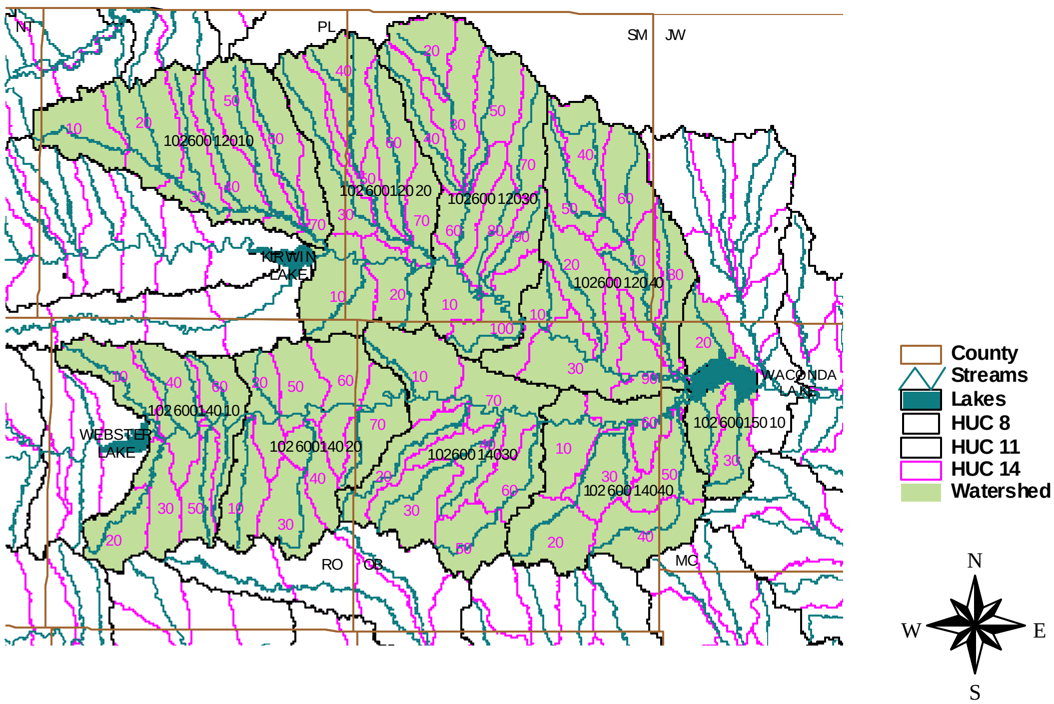
Covert Cr (19)

Kill Creek (Bloomington) (665)

Kill Cr (18)	E. Kill Cr (28)

Figure 1

Waconda Lake HUC 14



Designated Uses: Primary and Secondary Contact Recreation; Expected Aquatic Life Support; Drinking Water; Groundwater Recharge, Industrial Water Supply, Irrigation; Livestock Watering on Main Stem Segments

Food Procurement on all Main Stem Segments, except on segment 798 of the South Fork Solomon River

2002 303(d) Listing: Waconda Basin Streams

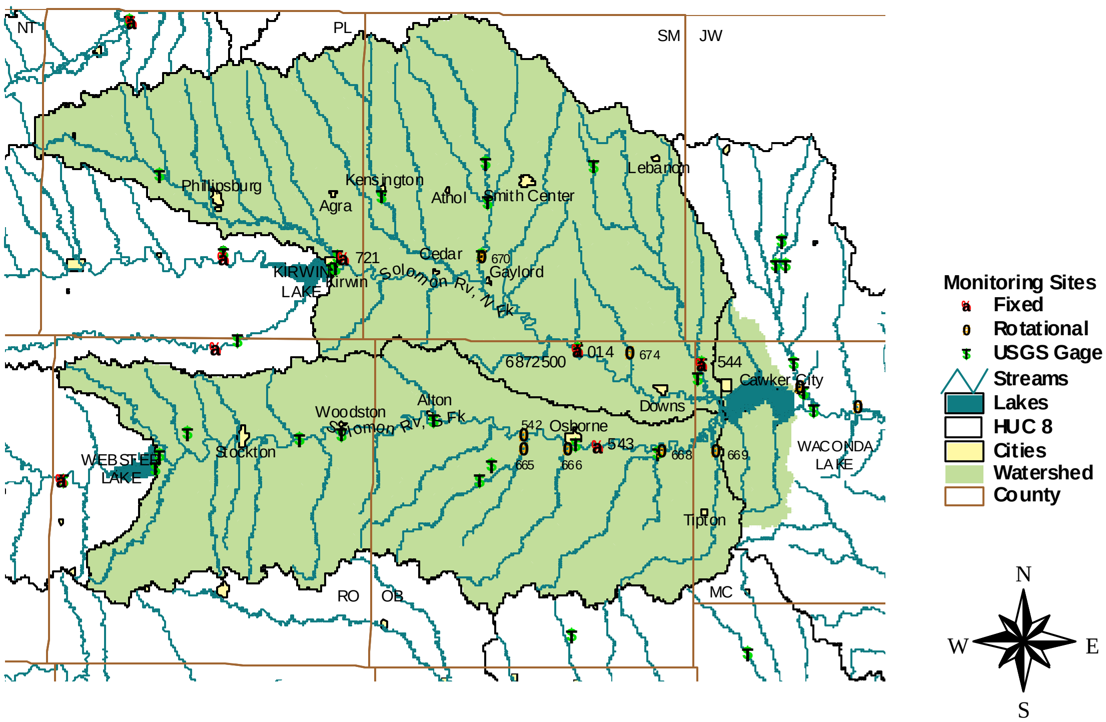
Impaired Use: Domestic Water Supply

Water Quality Standard: Domestic Water Supply: 250 mg/L at any point of domestic water supply diversion (K.A.R.28-16-28e(c) (3) (A)

In stream segments where background concentrations of naturally occurring substances, including chlorides and sulfates, exceed the domestic water supply criteria listed in table 1a in subsection (d), at ambient flow, due to intrusion of mineralized groundwater, the existing water quality shall be maintained, and the newly established numeric criteria for domestic water supply shall be the background concentration, as defined in K.A.R. 28-16-28b(e). Background concentrations shall be established using the methods outlined in the ‘‘Kansas implementation procedures: surface water quality standards,’’ as defined in K.A.R. 28-16-28b(ee), available upon request from the department. (K.A.R. 28-16-28e(c) (3)(B))

Figure 2

Waconda Lake TMDL Reference Map



2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT

Lake Monitoring Site: Station 018001 in Waconda Lake (Figure 2).

Period of Record Used: Six surveys during 1986 - 2001

Elevation Record: Waconda Lake at Glen Elder, KS (USGS Gage 06874200)

Stream Chemistry Monitoring Sites:

Monitoring and Flow Record Information for the Waconda Lake Basin

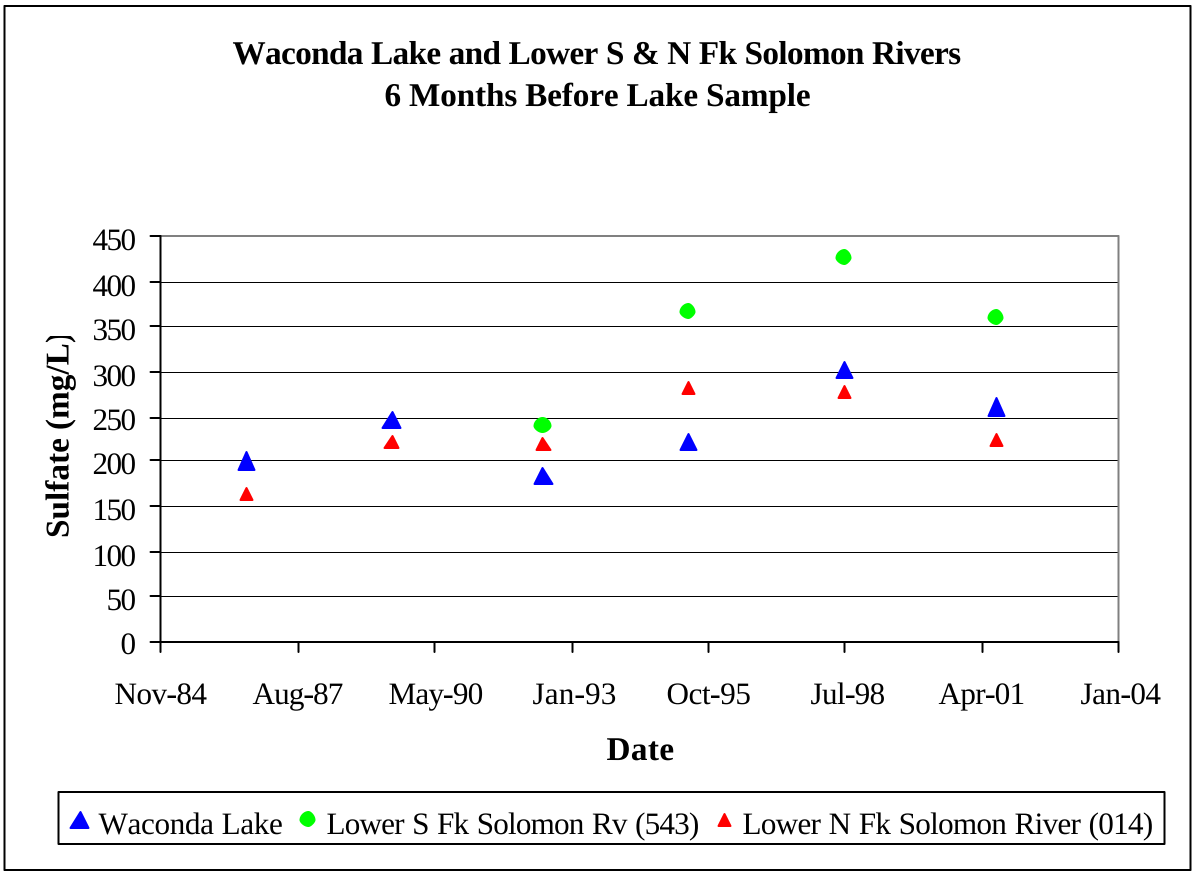
Monitoring Sites	Period of Record Used	Flow Record (USGS Gage)	Median Flows (cfs)
Station 014 at Portis (North Fork Solomon River)	1985 - 2002	North Fork Solomon River at Portis, KS (06872500)	34.7
Station 542 above Osborne (South Fork Solomon River)	1990 - 1998	South Fork Solomon River at Osborne, KS (06874000)	20.8
Station 543 below Osborne (South Fork Solomon River)	1990 - 2002	South Fork Solomon River at Osborne, KS (06874000)	20.8
Station 544 near Cawker City (Oak Creek)	1990 - 2001	Matched to flow duration for White Rock Cr nr Burr Oak (06853800)	8.0
Station 665 near Bloomington (Kill Creek)	1995 - 1999	Matched to flow duration for Salt C near Ada (06876700)	1.5
Station 666 near Osborne (Covert Creek)	1995 - 1999	Matched to flow duration for Salt C near Ada (06876700)	1.3
Station 668 near Corinth (Twin Creek)	1992 - 2000	Matched to flow duration for Salt C near Ada (06876700)	1.1
Station 669 near Cawker City (Carr Creek)	1992 - 2000	Matched to flow duration for White Rock Cr nr Burr Oak (06853800)	0.3
Station 670 near Gaylord (Beaver Creek)	1992 - 2000	Matched to flow duration for White Rock Cr nr Burr Oak (06853800)	7.1
Station 721 near Kirwin (Deer Creek)	1999 - 2001	Matched to flow duration for Bow Cr Nr Stockton (06871500)	5.3

Current Condition: The sulfate concentrations in Waconda Lake have been elevated every year since the 1995 monitoring period (Appendix A and table below). From 1986 through 1995, the average sulfate concentration was 212 mg/L. For the period of record that followed, the sulfate concentration was above the drinking water standard, averaging 282 mg/L.

Average Sulfate Concentrations in Waconda Lake

Date	Sulfate (mg/L)	Elevation (feet)
7/28/86	200.75	Active Pool = 1455.6
6/27/89	246.75	1451.02
7/8/92	183.75	1454.17
6/6/95	222.19	1466.84
7/14/98	302.90	1456.14
8/7/01	260.69	1455.21

Figure 3



The sulfate concentrations in the lake are consistently lower than the concentrations in the Lower South Fork Solomon River (Figure 3). The in-lake concentrations parallel the fluctuations in sulfate concentrations in the watershed. The highest levels of sulfate are seen in the tributaries of the Lower South Fork Solomon River, especially at stations 665, 666, 668, and 669 (Figures 4 & 5 and Appendix A). At station 543, the sulfate concentrations were significantly lower during drought years, from 1990 to 1992. The sulfate concentrations from stations 542 and 543, on matching dates, are not statistically significant. The average sulfate concentrations at the up-stream lakes are 324 mg/L for Webster Lake and 165 mg/L for Kirwin Lake.

Figure 4

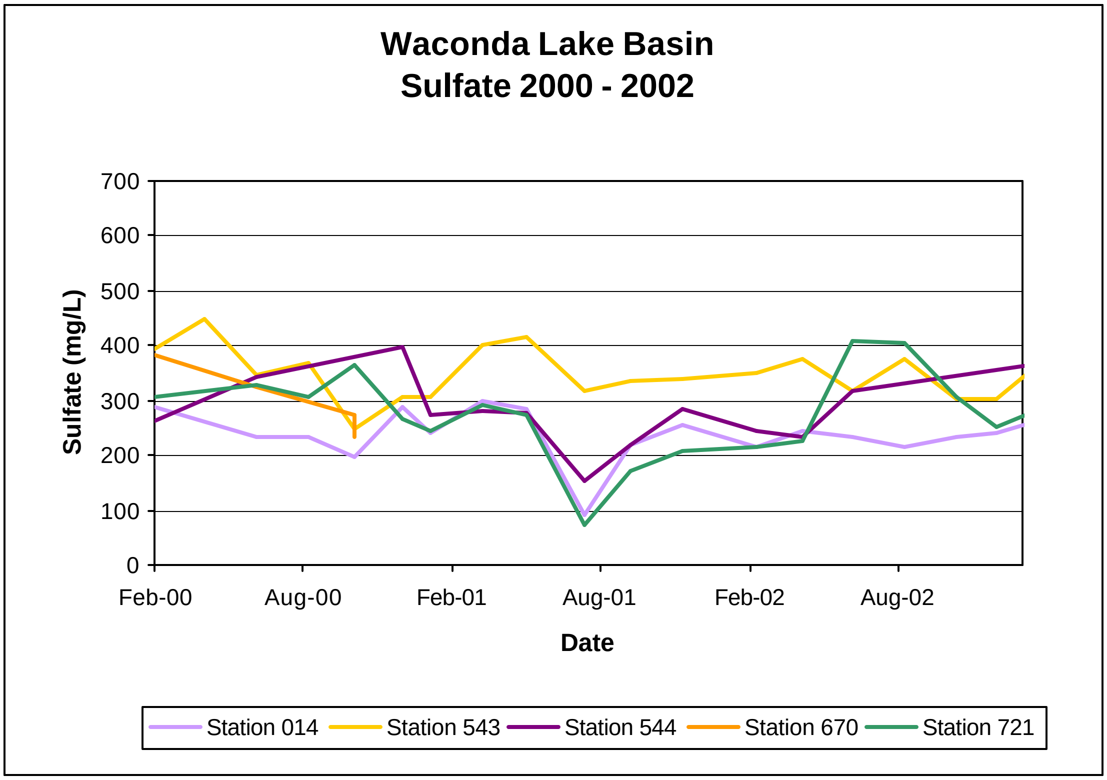
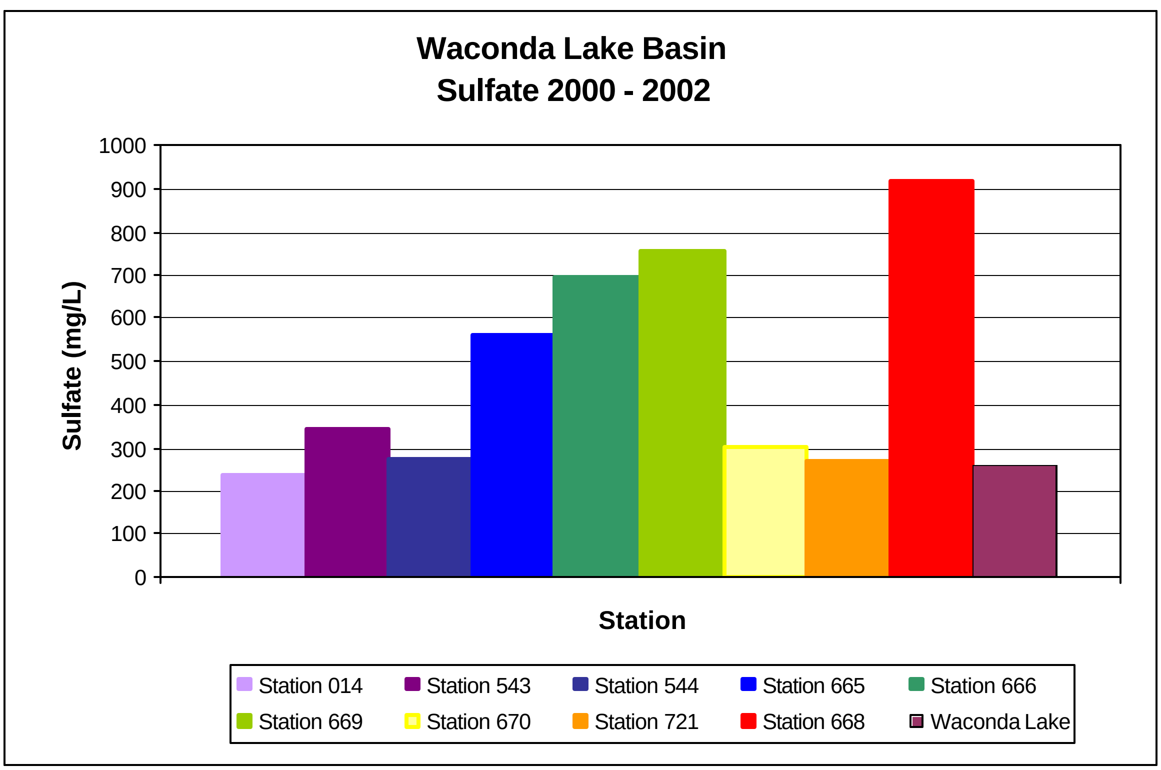


Figure 5



Since loading capacity varies as a function of the flow present in the stream, this TMDL represents a continuum of desired loads over all flow conditions, rather than fixed at a single value. Sample data for the sampling sites were categorized for each of the three defined seasons: Spring (Apr-Jul), Summer-Fall (Aug-Oct) and Winter (Nov-Mar). High flows and runoff equate to lower flow durations; baseflow and point source influences generally occur in the 75-99% range. A Load curve was established for the Domestic Water Supply criterion by multiplying the flow values along the curve by the applicable water quality criterion and converting the units to derive a load duration curve of tons of sulfate per day. This load curves represent the TMDL since any point along the curve represents water quality for the standard at that flow. Historic excursions from the water quality standard are seen as plotted points above the load curve. Water quality standards are met for those points plotting below the load duration curve (Appendix B).

Station 014: Excursions were seen in each of the three defined seasons and are outlined below. Eighteen percent of Spring samples and 27% of Summer-Fall samples were over the domestic supply criterion. Forty-five percent of Winter samples were over the criterion. Overall, 31% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	**Season**	**0 to 10%**	**10 to 25%**	**25 to 50%**	**50 to 75%**	**75 to 90%**	**90 to 100%**	**Cum Freq.**
Station 014 at Portis (North Fork Solomon River)	Spring	0	2	2	0	0	0	4/22 = 18%
	Summer	1	1	1	0	0	1	4/15 = 27%
	Winter	0	5	4	1	0	0	10/22 = 45%

Station 542: Excursions were seen in each of the three defined seasons and are outlined below. Fifty percent of Spring samples and 100% of Summer-Fall samples were over the domestic supply criterion. Eighty-three percent of Winter samples were over the criterion. Overall, 73% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated use.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	**Season**	**0 to 10%**	**10 to 25%**	**25 to 50%**	**50 to 75%**	**75 to 90%**	**90 to 100%**	**Cum Freq.**
Station 542 above Osborne (South Fork Solomon River)	Spring	2	0	1	0	0	0	3/6 = 50%
	Summer	0	0	2	0	1	0	3/3 = 100%
	Winter	2	1	1	1	0	0	5/6 = 83%

Station 543: Excursions were seen in each of the three defined seasons and are outlined below. Seventy-one percent of Spring samples and 73% of Summer-Fall samples were over the domestic supply criterion. Seventy-five percent of Winter samples were over the criterion. Overall, 73% of the samples were over

the criteria. This would represent a potential baseline condition of non-support of the impaired designated use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	Season	0 to 10%	10 to 25%	25 to 50%	50 to 75%	75 to 90%	90 to 100%	Cum Freq.
Station 543 below Osborne (South Fork Solomon River)	Spring	4	10	0	1	0	0	15/21 = 71%
	Summer	1	2	5	2	1	0	11/15 = 73%
	Winter	2	5	8	3	0	0	18/24 = 75%

Station 544: Excursions were seen in each of the three defined seasons and are outlined below. Forty-eight percent of Spring samples and 33% of Summer-Fall samples were over the domestic supply criterion. Seventy-seven percent of Winter samples were over the criterion. Overall, 56% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	Season	0 to 10%	10 to 25%	25 to 50%	50 to 75%	75 to 90%	90 to 100%	Cum Freq.
Station 544 near Cawker City (Oak Creek)	Spring	1	3	3	1	2	0	10/21 = 48%
	Summer	0	0	0	3	1	0	4/12 = 33%
	Winter	0	3	8	3	3	0	17/22 = 77%

Station 665: Excursions were seen in each of the three defined seasons and are outlined below. Thirty-three percent of Spring samples and 100% of Summer-Fall samples were over the domestic supply criterion. One hundred percent of Winter samples were over the criterion. Overall, 80% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	Season	0 to 10%	10 to 25%	25 to 50%	50 to 75%	75 to 90%	90 to 100%	Cum Freq.
Station 665 near Bloomington (Kill Creek)	Spring	0	0	1	0	0	0	1/3 = 33%
	Summer	0	0	2	1	0	0	3/3 = 100%
	Winter	0	1	3	0	0	0	4/4 = 100%

Station 666: Excursions were seen in each of the three defined seasons and are outlined below. Seventy-five percent of Spring samples and 100% of Summer-Fall samples were over the domestic supply criterion. One hundred percent of Winter samples were over the criterion. Overall, 91% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated

use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	Season	0 to 10%	10 to 25%	25 to 50%	50 to 75%	75 to 90%	90 to 100%	Cum Freq.
Station 666 near Osborne (Covert Creek)	Spring	1	1	1	0	0	0	3/4 = 75%
	Summer	0	0	2	1	0	0	3/3 = 100%
	Winter	0	1	3	0	0	0	4/4 = 100%

Station 668: Excursions were seen in each of the three defined seasons and are outlined below. Sixty percent of Spring samples and 100% of Summer-Fall samples were over the domestic supply criterion. One hundred percent of Winter samples were over the criterion. Overall, 80% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	Season	0 to 10%	10 to 25%	25 to 50%	50 to 75%	75 to 90%	90 to 100%	Cum Freq.
Station 668 near Corinth (Twin Creek)	Spring	0	0	2	1	0	0	3/5 = 60%
	Summer	0	0	0	1	0	0	1/1 = 100%
	Winter	1	0	2	0	1	0	4/4 = 100%

Station 669: Excursions were seen in each of the three defined seasons and are outlined below. Fifty percent of Spring samples and 100% of Summer-Fall samples were over the domestic supply criterion. One hundred percent of Winter samples were over the criterion. Overall, 78% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	Season	0 to 10%	10 to 25%	25 to 50%	50 to 75%	75 to 90%	90 to 100%	Cum Freq.
Station 669 near Cawker City (Carr Creek)	Spring	0	0	1	0	1	0	2/4 = 50%
	Summer	0	0	2	1	1	0	4/4 = 100%
	Winter	0	0	0	1	0	0	1/1 = 100%

Station 670: Excursions were seen in each of the three defined seasons and are outlined below. Fifty percent of Spring samples and 50% of Summer-Fall samples were over the domestic supply criterion. Eighty-three percent of Winter samples were over the criterion. Overall, 64% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	Season	0 to 10%	10 to 25%	25 to 50%	50 to 75%	75 to 90%	90 to 100%	Cum Freq.
Station 670 near Gaylord (Beaver Creek)	Spring	0	0	1	0	2	0	3/6 = 50%
	Summer	0	0	0	0	1	0	1/2 = 50%
	Winter	0	0	2	1	2	0	5/6 = 83%

<u>Station 721:</u> Excursions were seen in each of the three defined seasons and are outlined below. Fifty percent of Spring samples and 75% of Summer-Fall samples were over the domestic supply criterion. Sixty-six percent of Winter samples were over the criterion. Overall, 64% of the samples were over the criteria. This would represent a potential baseline condition of non-support of the impaired designated use, if a point of diversion for water supply was present along the river.

NUMBER OF SAMPLES OVER SULFATE STANDARD OF 250 mg/L BY FLOW AND SEASON

Station	Season	0 to 10%	10 to 25%	25 to 50%	50 to 75%	75 to 90%	90 to 100%	Cum Freq.
Station 721 near Kirwin (Deer Creek)	Spring	0	1	0	1	0	0	2/4 = 50%
	Summer	0	0	1	1	0	1	3/4 = 75%
	Winter	0	1	2	1	0	0	4/6 = 66%

Interim Endpoints of Water Quality (Implied Load Capacity) at Waconda Lake and Stations 014, 542, 543, 544, 665, 666, 668, 669, 670, and 721 over 2008 - 2012:

To ensure that the domestic water supply is protected, the desired endpoint will be to maintain average sulfate concentrations at or below 250 mg/L in Waconda Lake.

Current Condition and Reductions for Waconda Lake

Parameter	Current Condition (1995 - 2001)	TMDL	Reduction
Sulfate (mg/L)	282	250	3%

The ultimate endpoint for this TMDL will be to achieve the Kansas Water Quality Standards fully supporting Drinking Water Use. This TMDL will, however, be phased. The current standard of 250 mg/L of sulfate was used to establish the TMDL. However, the Waconda Lake basin is affected by the weathering of Cretaceous bedrock. As such, the watershed's main stems and many of its tributaries have elevated sulfate levels from this natural source. In some cases, the elevation beyond natural sulfate levels can be attributed to long term consumptive use of water by irrigation. This is the case for the North and South Forks of the Solomon River and may be a factor in the higher sulfate seen on the North Fork tributaries of Oak Creek, Beaver Creek and Deer Creek. However, the tributaries to the South Fork are marked by a lack of irrigation and these tributaries overlie the Cretaceous bedrock. This natural background source of sulfate, makes achievement of the 250 mg/l criterion problematic across varied flow conditions at Stations 665, 666, 668, and 669.

The average sulfate concentrations at Station 014, 542, 543, 544, 670, and 721 for flows greater and less than the median is either not significantly different from the Phase One endpoint or has been altered by irrigation impacts, therefore, the 250 mg/l endpoint will apply to all flows on the South Fork Solomon River, the North Fork Solomon River and tributaries to the North Fork. Likewise, the background concentration of Waconda Lake is not significantly different than the water quality standard, and thus the 250 mg/L endpoint will be used. At Stations 665, 666, 668, and 669, since the Standard is not achievable because of natural contributions to the sulfate load, an alternative endpoint is needed.

Kansas Implementation Procedures for Surface Water allow for a numerical criterion based on natural background to be established from samples taken at flows less than median in-stream flow. The Procedures also allow for alternate calculations if concentrations are not proportional to flow. Exceedances on the South Fork Solomon tributaries occur across all flow conditions, thus, the samples taken below median flow do not represent the complete loading situation. The specific stream criteria to supplant the general standard will be developed concurrent with Phase One of this TMDL following the appropriate administrative and technical Water Quality Standards processes.

A tentative endpoint has been developed from currently available information at water quality monitoring stations 665, 666, 668, and 669. The average sulfate concentration at those stations of the samples collected at all flows less than the median flow will be used and are as follows:

Background Concentrations in Waconda Lake Watershed

Station	Median Flow (cfs)	Background (mg/L)
Station 665 near Bloomington (Kill Creek)	1.5	540
Station 666 near Osborne (Covert Creek)	1.3	610
Station 668 near Corinth (Twin Creek)	1.1	730
Station 669 near Cawker City (Carr Creek)	0.3	690

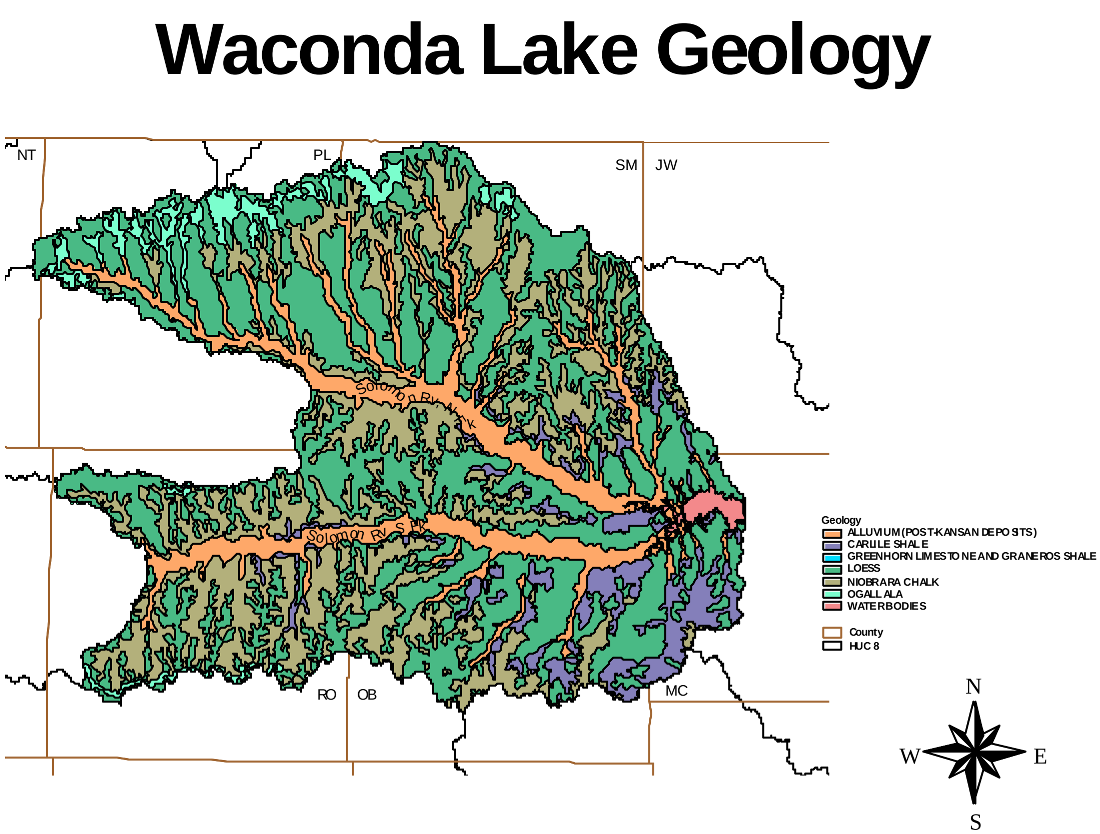
The Phase Two TMDL will be based on the future standard applied to these flows within the contributing portions of the Waconda Lake Basin watershed to Stations 665, 666, 668, and 669.

Seasonal variation has been incorporated in this TMDL through the documentation of the seasonal consistency of elevated sulfate levels. Achievement of the endpoints indicates loads are within the loading capacity of the stream, water quality standards are attained and full support of the designated uses of the stream has been restored.

3. SOURCE INVENTORY AND ASSESSMENT

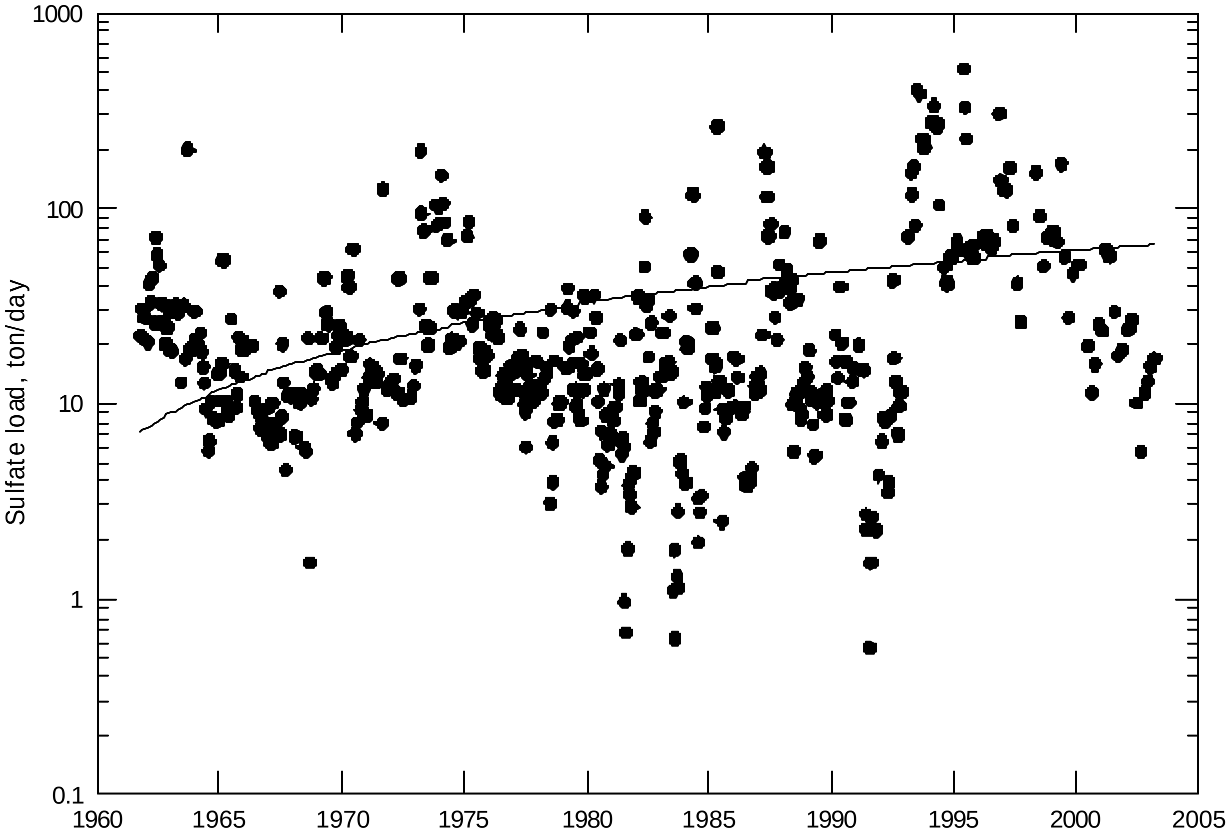
Background Conditions: The main natural source of sulfate in the Lower North Fork and South Fork Solomon Rivers and Waconda Lake are from the weathering of Cretaceous bedrock that underlies the drainage basin of Waconda Lake (Figure 3). Oxidation of the sulfide in pyrite (iron sulfide) and dissolution of small amounts of gypsum (hydrous calcium sulfate), especially in selected units of the Smoky Hill Member of the Niobrara Chalk and the Carlile Shale during the weathering of the bedrock, increase the sulfate concentration of water moving through the subsurface. This water then discharges directly from the weathered bedrock into streams or into overlying alluvial sediments before entering streams. Evapotranspiration consumption of water in the drainage basin and evaporation from the surface of streams, Kirwin and Webster lakes upstream, and Waconda Lake have increased the sulfate concentration of the surface water.

Figure 6



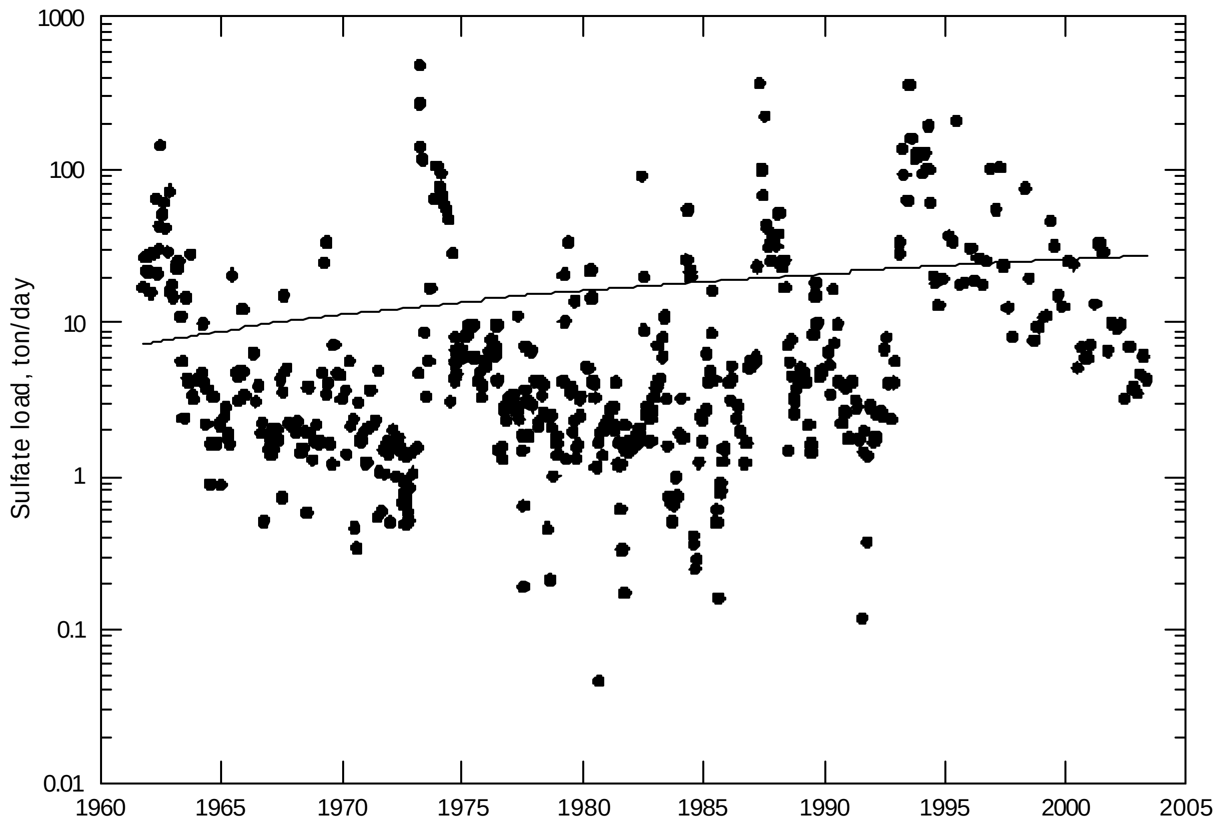
Factors controlling variations in sulfate: The record of water quality for Waconda Lake indicates that the sulfate concentration has increased during the period of observation (Boxplot in Appendix A); the increase is statistically significant. The sulfate content has varied appreciably during this time. Large fluctuations in the amount of rainfall that runs off into lakes can cause variations in the dissolved solids content of lake water. The runoff following substantial rainstorms is appreciably fresher than most of the baseflow of streams and can dilute the dissolved solids concentration of lake water as it fills the lake. However, the sulfate concentration does not appear to be well correlated with the volume of water stored in Waconda Lake. (See the "Average Sulfate Concentrations in Waconda Lake" table in the Current Condition Section). Evaporation of water from the surface of Waconda Lake also increases the sulfate content. Although the evaporation would be an additional factor causing the lake water increase in sulfate concentration, Figure 3 suggests that the increases in the sulfate level of the river inflow water are more important than lake evaporation.

Figure 7. Variation in sulfate load of the North Fork Solomon River at Portis (station 014) during 1961-2003. The line is a linear regression for the data.



There is a long-term trend of increasing sulfate load for both the North Fork Solomon River at Portis and the South Fork Solomon River at or below Osborne (Figures 7 and 8, respectively). Although the correlation coefficients for the linear regressions are low, the increasing trends in the sulfate load for both locations are statistically significant. There is usually an inverse relationship between the flow and the sulfate content of river water in Kansas and a power curve typically fits this relationship better than other functions. Although this relationship describes the North Fork Solomon River data at Portis during 1961-1980, there is not a clear relationship between flow and sulfate content for 1981-2003 (Figure 11). The usual inverse relationship between flow and sulfate content for rivers in Kansas is generally expressed by the power-curve fit of the 1961-1980 data for the river at Osborne (Figure 12). However, the power-curve fit for the 1981-2003 data for the river at Osborne and below Osborne appears to show an opposite relationship for the flow and sulfate concentration. The higher sulfate levels in the river occur at moderate and higher flows rather than at low flows.

Figure 8. Variation in sulfate load of the South Fork Solomon River at (station 015) and below Osborne (station 543) during 1961-2003. The line is a linear regression for the data.



The most probable explanation for the long-term increase in the sulfate content of the lower North and South forks of the Solomon River, and thus, of Waconda Lake, (Figure 9 and 10) is a combination of the increase in the sulfate concentration of the upper North and South forks of the Solomon River and Kirwin and Webster lakes combined with an increase in the lower North and South forks related to water use and consumption. There are no known, substantial human sources of sulfate or other major dissolved constituents that were added to the system during this time that could account for the increases. Evaporation and plant transpiration associated with irrigation in the river valleys of the North and South forks of the Solomon River consume water and leave dissolved constituents in the residual water, thereby increasing the constituent concentrations. Transpiration by phreatophytes in the river valley also consumes water and increases the dissolved solids of shallow groundwater in the alluvial aquifer.

Figure 9. Variation in sulfate content of the lower North Fork Solomon River at Portis during 1961-2003 (USGS and KDHE data) and at Downs during 2002-2003 (KGS data). The linear regression is for the data at Portis.

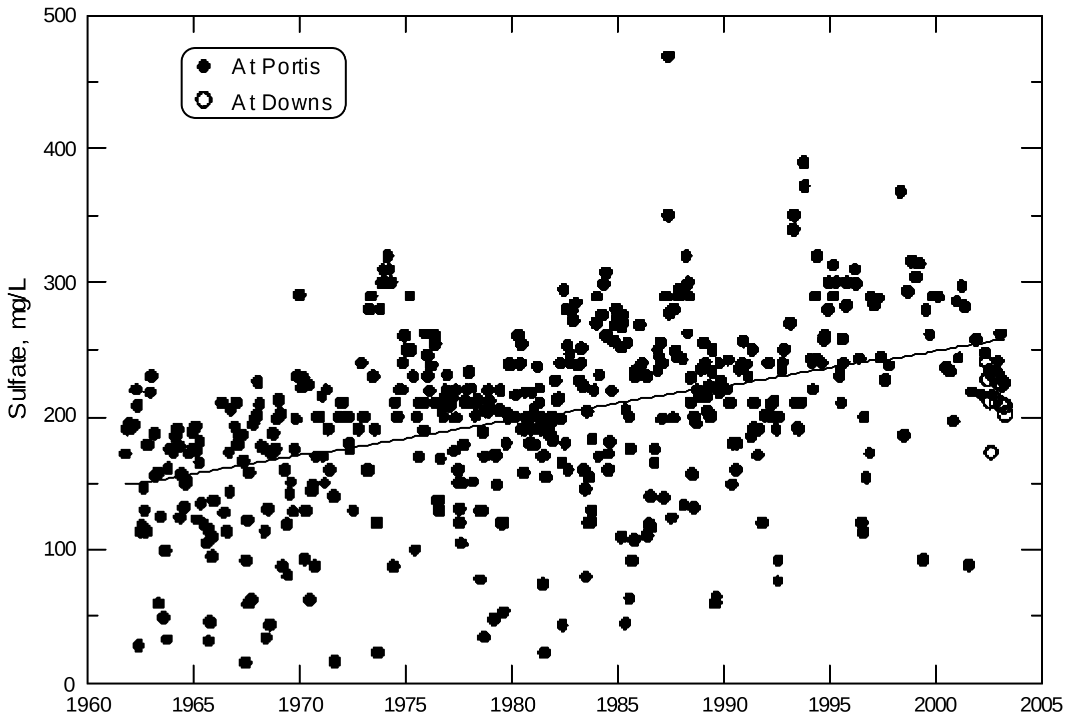


Figure 10. Variation in sulfate concentration of the lower South Fork Solomon River at Osborne during 1961-1994 (USGS and KDHE data), below Osborne during 1990-2003 (KDHE data), and near Corinth during 2002-2003 (KGS data). The linear regressions are for the first two data sets.

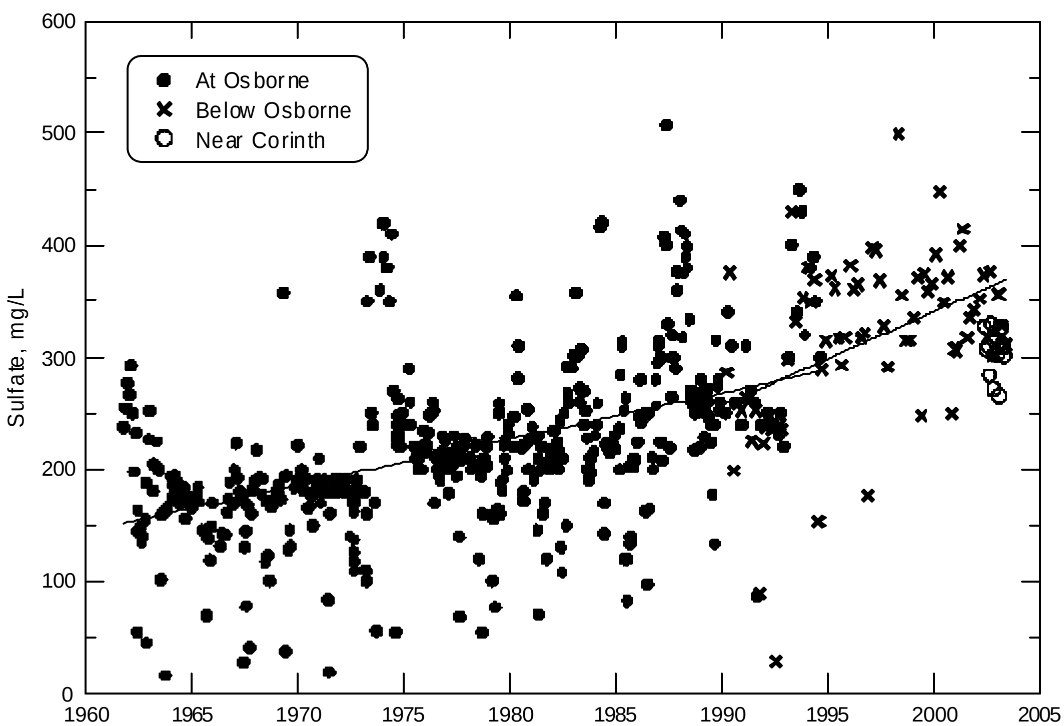
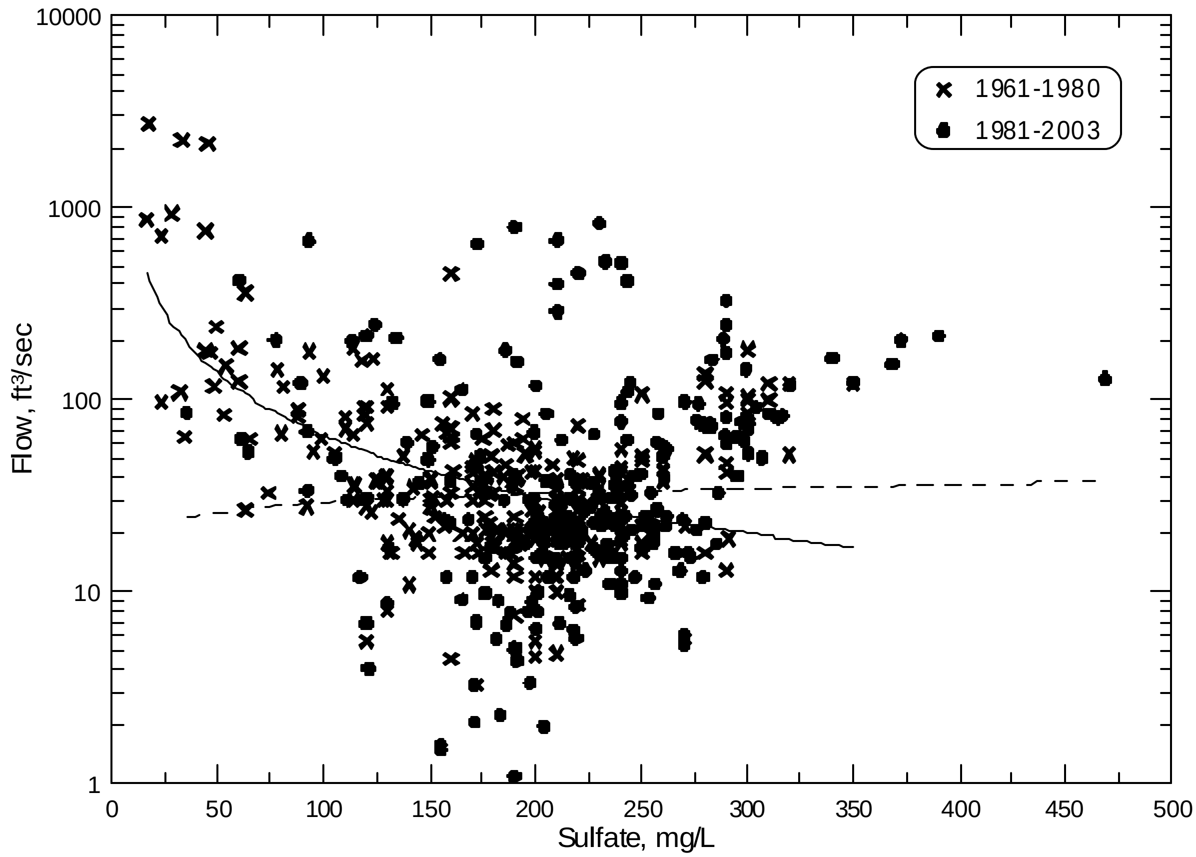


Figure 11 Flow versus sulfate concentration for the lower North Fork Solomon River at Portis during 1961-1980 and 1981-2003 (USGS and KDHE data). The solid and dashed lines are power curve fits to the 1961-1980 and 1981-2003 data sets, respectively.

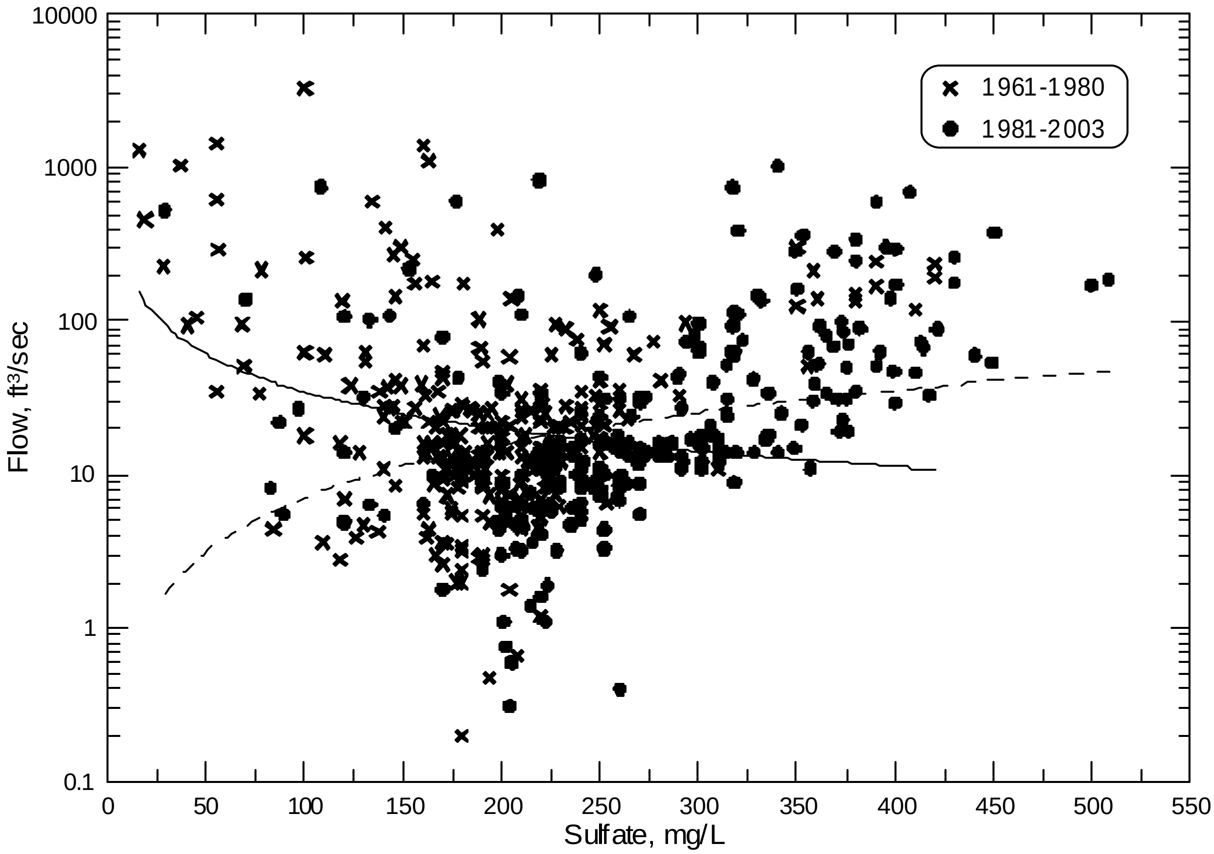


Irrigation: There are many irrigation wells in the alluvial aquifer in the river valleys of the lower North and South forks of the Solomon River upstream of Waconda Lake. See the point of diversion map in Figure 12 and geology maps in Appendix D. Irrigation reports from 2001 show the following:

Water Use Statistics for Each Monitoring Site

Monitoring Sites	Surface Water		Groundwater	
	Area (acres)	**Volume (acre-feet)**	**Area (acres)**	**Volume (acre-feet)**
Station 014 at Portis (North Fork Solomon River)	1,054	800	4,551	3,345
Station 542 above Osborne (South Fork Solomon River)	207	15,197	2,411	1,432
Station 543 below Osborne (South Fork Solomon River)	360	15,311	2,513	1,485
Station 544 near Cawker City (Oak Creek)	90	65	78	83
Station 665 near Bloomington (Kill Creek)	N/A	N/A	N/A	N/A
Station 666 near Osborne (Covert Creek)	0	0	0	0
Station 668 near Corinth (Twin Creek)	0	0	0	0
Station 669 near Cawker City (Carr Creek)	0	0	0	0
Station 670 near Gaylord (Beaver Creek)	67	64	0	0
Station 721 near Kirwin (Deer Creek)	35	12	501	371

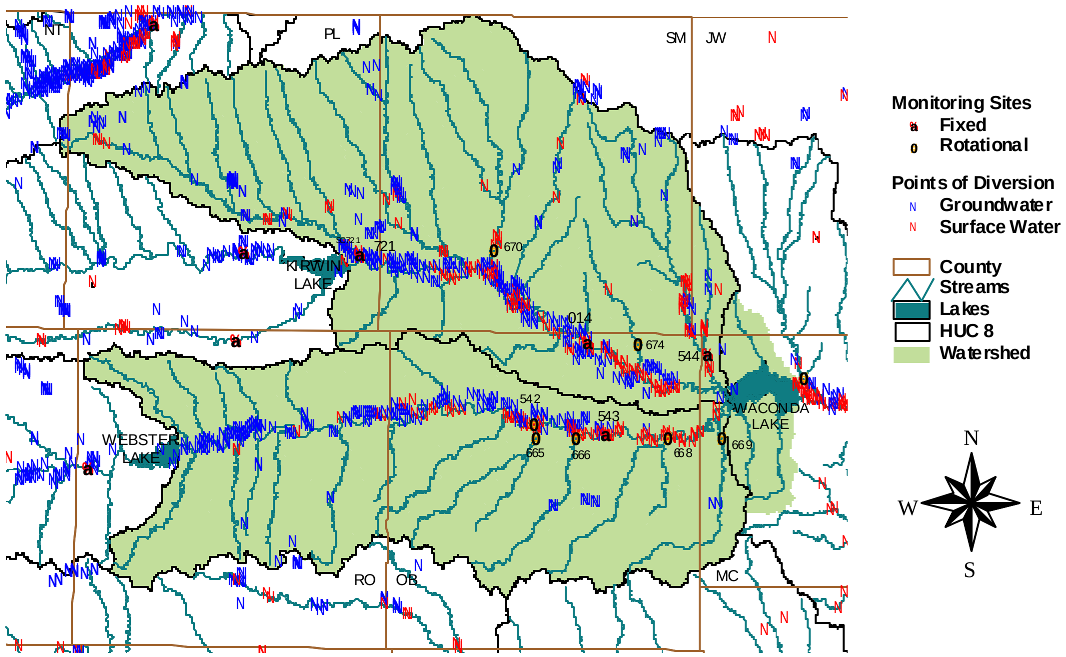
Figure 12. Flow versus sulfate content for the South Fork Solomon River at and below Osborne during 1961-1980 and 1981-2003 (USGS and KDHE data). The solid and dashed lines are power curve fits to the 1961-1980 and 1981-2003 data sets, respectively.



In addition, surface water from the lakes and the rivers are diverted for irrigation use in the river valleys. The irrigation increases the rate of supply of dissolved solids to the soils of the irrigated land in the river valley. Much of the irrigation water applied to the crops is consumed by evapotranspiration, leaving the dissolved salts in the soil or soil moisture. Some irrigation water also returns to the river. Part of the salts in the irrigated soils is leached below the root zone while much of the salt remains within the root zone of the soil. Heavy rainfall first must saturate shallow soil before substantial runoff occurs. The rainwater infiltrating the shallow soil dissolves readily soluble salts. Water in the saturated soil moves laterally down slope in the soil if the rainfall rate is great enough. The saturated soil water then leaves the fields in small surface drainages to form runoff to the river tributaries. The water that infiltrates through the soil to the water table also carries dissolved salts. The shallow groundwater with increased dissolved solids slowly moves towards the river, particularly during low flow periods when the river level is low, and eventually discharges into the channel. The buildup of substantial amounts of salts in irrigated soils and underlying shallow groundwaters generally requires several or more years. Thus, there is a lag time between the transport of dissolved salts, in surface water and groundwater supplies used for irrigation, to the irrigated cropland and then the appearance of substantial amounts of the salts in the river and lake water. Irrigation based on pumping wells in western Kansas increased appreciably from the 1950s to the 1980s. The surface water diversions below Kirwin and Webster lakes for irrigation use began after the lakes reached their multipurpose pool levels in 1957. The increase of sulfate in the North and South forks of the Solomon River and Waconda Lake fits the timing of the increase in irrigation and the lag time for buildup and transport of the additional dissolved salts to both the upper and lower North and South Forks of the river system.

Figure 13

Waconda Lake Points of Diversion

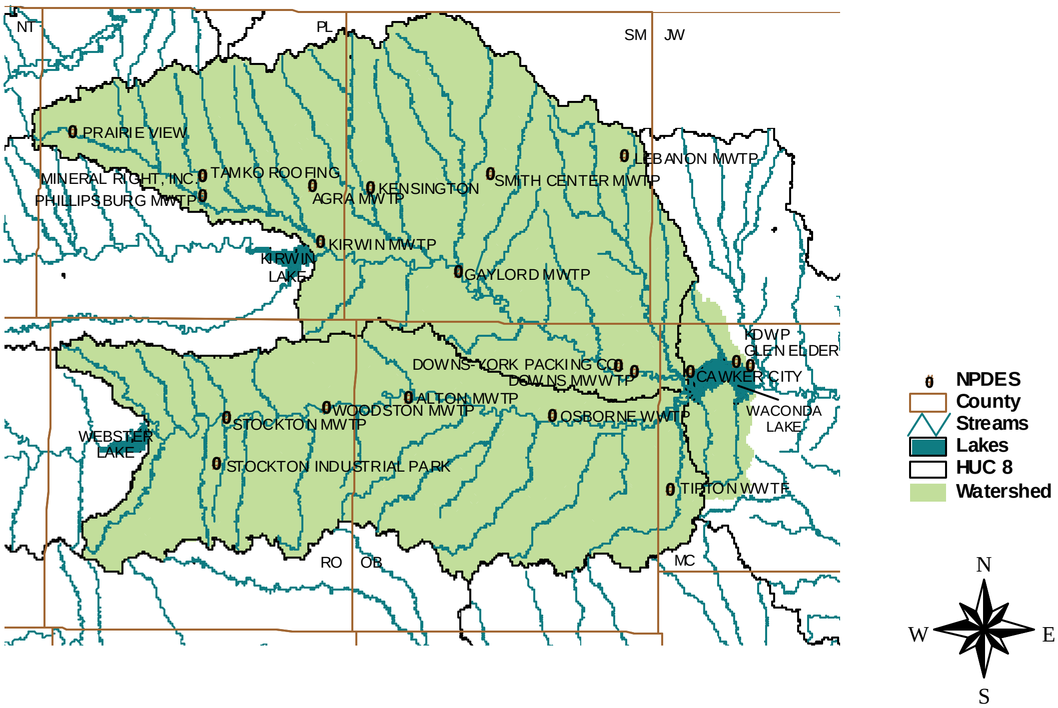


Phreatophytes: Consumption of water by phreatophytes (high water-use trees) in the valleys of the North and South forks of the Solomon River increases the dissolved solids concentration of groundwater in the alluvial aquifer. If the area of phreatophyte covered valley has increased from the middle to the later part of the 20th century in the upper and lower North and South forks of the Solomon River, phreatophyte impacts on water loss and dissolved solids concentration could be partially responsible for the long-term increase in sulfate concentration in the river and Waconda Lake.

NPDES: Twenty permitted waste treatment facilities are located within the watershed (Figure 14). Eleven are non-overflowing lagoons that are prohibited from discharging. The non-overflowing lagoons may contribute to the load under extreme precipitation events (flow durations exceeded under 5 percent of the time). Such events would not occur at a frequency or for a duration sufficient to cause an impairment in the watershed. Any anthropogenic sulfate sources or hydrologic modifications increasing the sulfate concentration would be minor in comparison with the sulfate coming from natural sources.

Figure 14

Waconda Lake NPDES Sites



Since none of the municipal NPDES sites in the watershed are currently required to monitor for sulfate in their effluent, average sulfate concentrations for municipal sources were estimated based on the sulfate in their influent. For mechanical plants, a one to one ratio was used to estimate the sulfate in effluent from the cities in the watershed's finished water. See Appendix C for the wasteload allocation calculations. Tamko Roofing Products, Inc. is permitted to discharge a daily average of 250 mg/L.

Waste Treatment Plants in the Waconda Lake Watershed

Kansas Permit Number	Name	Type	Design Capacity (MGD)	SO_4 Wasteload Allocation
F-SO08-OO01	CAWKER CITY - WACONDA RES.	Three-cell lagoon	0.085	0.086 tons/day
I-SO12-NP01	DOWNS-YORK PACKING CO.	six-cell lagoon	non-overflowing	0 tons/day
I-SO31-PO01	TAMKO ROOFING PRODUCTS,INC.	aerated cells	monitor (average 0.027 in 2002)	0.028 tons/day
I-SO41-NO02	STOCKTON INDUSTRIAL PARK	two wastewater systems	non-overflowing	0 tons/day
M-SO01-NO01	AGRA MWTP	Three-cell lagoon	non-overflowing	0 tons/day
M-SO02-NO01	ALTON MWTP	Three-cell lagoon	non-overflowing	0 tons/day
M-SO12-OO01	DOWNS MWTP	Trickling Filter	0.15	0.026 tons/day

M-SO15-NO02	GAYLORD MWTP	Three-cell lagoon	non-overflowing	0 tons/day
M-SO18-NO02	KDWP - GLEN ELDER(EAST)	Three-cell lagoon	non-overflowing	0 tons/day
M-SO18-NO03	KDWP - GLEN ELDER(WEST)	Two-cell Lagoon	non-overflowing	0 tons/day
M-SO21-OO02	KENSINGTON	Three-cell lagoon	0.055	0.076 tons/day
M-SO22-NO01	KIRWIN MWTP	Two-cell Lagoon	non-overflowing	0 tons/day
M-SO23-NO01	LEBANON MWTP	Three-cell lagoon	non-overflowing	0 tons/day
M-SO29-OO02	OSBORNE WWTP	Four-cell Lagoon	0.286	0.336 tons/day
M-SO31-OO01	PHILLIPSBURG MWTP	Activated Sludge	0.35	0.397 tons/day
M-SO33-NO01	PRAIRIE VIEW	Two-cell Lagoon	non-overflowing	0 tons/day
M-SO38-IO01	SMITH CENTER MWTP	Activated Sludge	0.5	0.522 tons/day
M-SO41-OO01	STOCKTON MWTP	Activated Sludge	0.275	0.406 tons/day
M-SO42-OO01	TIPTON WWTF	Three-cell lagoon	0.023	0.028 tons/day
M-SO43-NO01	WOODSTON MWTP	Three-cell lagoon	non-overflowing	0 tons/day
		Total	**1.751**	**1.905 tons/day**

Oil-field Brine: Oil-field brine in Kansas that was disposed at or near the surface in the past generally has a sulfate concentration that is relatively low in comparison with the high chloride content. Thus, oil-brine contamination in the drainage basin is not expected to be a significant source of sulfate in the lake water.

Contributing Runoff: The watershed's average soil permeability is 1.3 inches/hour according to NRCS STATSGO database. About 90.5% of the watershed produces runoff even under relatively low (1.5''/hr) potential runoff conditions. Runoff is chiefly generated as infiltration excess with rainfall intensities greater than soil permeabilities. As the watersheds' soil profiles become saturated, excess overland flow is produced. Generally, storms producing less than 0.5"/hr of rain will generate runoff from 4.6% of this watershed, chiefly along the stream channels.

4. ALLOCATION OF POLLUTANT REDUCTION RESPONSIBILITY

The source assessment has ascertained that natural sulfate loading within the watershed is overwhelmingly responsible for the excursions seen at the monitoring stations on certain tributaries located within the Waconda Lake basin. In other cases, the elevated sulfate concentrations along the North Fork and South Fork Solomon Rivers is likely exacerbated by historic consumption of water by irrigation.

Point and Non-Point Sources: In the table below, under Phase One, the Wasteload and Load Allocations are given for all the stations included in this TMDL. The total Wasteload Allocation entering Waconda Lake is 1.90 tons per day. Under Phase Two, Load Allocations were calculated from the applicable background concentrations designated in the endpoint. Background concentrations were not determined for stations 014, 542, 543, 544, 670, and 721 and the inflow into Waconda Lake, because the sulfate concentrations are not significantly different from the Phase One endpoint. Phase Two Wasteload Allocations were established based on the concentration of sulfate assumed to be in each discharger's effluent, reflecting their source water content. No allowance was made for evaporation. Calculations for Wasteload Allocations are provided in Appendix C.

Allocations for Waconda Lake Watershed

Phase One: 250 mg/L Endpoint											
Station	014	542	543	544	665	666	668	669	670	721	Inflow
Load Capacity (tons/day)	23.42	14.04	14.04	5.40	1.02	0.87	0.77	0.20	4.81	3.58	725.21
Wasteload Allocation (tons/day)	0.08	0.41	0.34	0.00*	0.00*	0.00*	0.00*	0.03	0.52	0.42	0.11
Load Allocation (tons/day)	23.34	13.63	13.70	5.40	1.02	0.87	0.77	0.17	4.28	3.15	725.10
Phase Two: Background											
Station	014	542	543	544	665	666	668	669	670	721	Inflow
Background Concentration (mg/L)	Phase I	Phase I	Phase I	Phase I	540	610	730	690	Phase I	Phase I	Phase I
Median Flow (cfs)	34.70	20.80	20.80	8.00	1.51	1.30	1.14	0.30	7.12	5.30	1074.38
Load Capacity (tons/day)					2.20	2.12	2.25	0.55			
Wasteload Allocation (tons/day)					0.00*	0.00*	0.00*	0.03			
Load Allocation (tons/day)					2.20	2.12	2.25	0.52			

* Should future point sources be proposed in the subwatershed and discharge into the impaired segments, the current wasteload allocation will be revised by adjusting current load allocations to account for the presence and impact of these new point source dischargers.

Defined Margin of Safety: The Margin of Safety provides some hedge against the uncertainty of loading and the sulfate endpoints for the Waconda Lake Watershed. The municipalities discharging to the Lower North and South Fork Solomon Rivers do not add sulfate to their wastewaters, therefore, the sulfate loads added by those facilities reflect the sulfate content of their source water. Because of the relative small volumes of discharge associated with the facilities (for Stockton, Osborne and Philipsburg, comprising 1.4 cfs of the 2.7 cfs of design flow, effectively raise ambient stream levels 3-6 mg/l), the unlikelihood of the design flows of the individual point sources and resulting wasteloads reaching the monitoring stations because of transit losses of flow and diversion by intervening irrigation, the stagnant or declining population bases of municipalities and the prevalence of exceedances at high flows, where wasteload impacts are negligible, the Margin of Safety implicitly assures the Wasteload Allocations will not cause an exceedance of the endpoint of this TMDL.

There are varying degrees of impact on sulfate levels from historic irrigation within the drainage of Waconda Lake. In the long term, the Load Allocations established by this TMDL reflect either the existing water quality standard or the background concentrations. The Margin of Safety implicitly assures these Load Allocations will achieve the endpoints of the TMDL through policies and objectives established under the Kansas Water Plan. Two objectives under the State Water Plan call for, by 2010; 1) reduction of water level decline rates within the Ogallala aquifer and implementation of enhanced water management in targeted areas; and, 2) reduction in the number of irrigation points of diversion for which the amount of water applied in acre-feet per acre exceeds an amount considered reasonable for the area and those [irrigation points of diversion] that overpump the amount authorized by their water rights. Pursuit of these two water conservation objectives will have water quality benefits, including assuring excessive irrigation will not directly or indirectly load surface waters with residual salts, thereby causing endpoints to be non-attained.

State Water Plan Implementation Priority: Because the sulfate impairment in Waconda Lake basin is primarily from natural geologic sources, this TMDL will be a Low Priority for implementation.

Unified Watershed Assessment Priority Ranking: Waconda Lake watershed lies within the Lower North Fork Solomon (HUC 8: 10260012) with a priority ranking of 34 (Medium Priority for restoration), Lower South Fork Solomon (HUC 8: 10260014) with a priority ranking of 45 (Medium Priority for restoration), and Solomon River (HUC 8: 10260015) with a priority ranking of 23 (High Priority for restoration).

Priority HUC 11s: Because of the natural geologic contribution of this impairment, the reach and tributaries of the South Fork Solomon River below Osborne will be a priority for investigating irrigation management.

5. IMPLEMENTATION

Desired Implementation Activities

1. Monitor any anthropogenic contributions of sulfate loading to the lake and rivers.
2. Establish alternative background criteria.
3. Assess likelihood of the lake and rivers being used for domestic uses.
4. Evaluate irrigation management practices for reducing salt leaching.

Implementation Programs Guidance

NPDES and State Permits - KDHE

a. Municipal permits for facilities in the watershed will be renewed after 2004 with annual sulfate monitoring and any excessive sulfate discharge will have appropriate permit limits which does not increase the ambient background levels of sulfate.

Non-Point Source Pollution Technical Assistance - KDHE

a. Evaluate any potential anthropogenic activities which might contribute sulfate to the lake as part of an overall Watershed Restoration and Protection Strategy.
b. Evaluate impact of irrigation return flows on sulfate loading to streams.

Water Quality Standards and Assessment - KDHE

a. Establish background levels of sulfate for the rivers and tributaries.

Use Attainability Analysis - KDHE

a. Consult with Division of Water Resources on locating existing or future domestic points of diversion from Waconda Lake for drinking water purposes.

Subbasin Management - DWR

a. Evaluate Best Management Practices for irrigation which decrease salt loading to streams.

Time Frame for Implementation: Development of a background level-based water quality standard should be accomplished with the next water quality standards revision.

Targeted Participants: Primary participants for implementation will be KDHE and DWR.

Milestone for 2008: The year 2008 marks the midpoint of the ten-year implementation window for the watershed. At that point in time, additional monitoring data from Waconda Lake will be reexamined to confirm the impaired status of the lake and the suggested background concentration. Should the case of impairment remain, source assessment, allocation and implementation activities will ensue.

Delivery Agents: The primary delivery agents for program participation will be the Kansas Department of Health and Environment and Division of Water Resources.

Reasonable Assurances:

Authorities: The following authorities may be used to direct activities in the watershed to reduce pollutants.

1. K.S.A. 65-171d empowers the Secretary of KDHE to prevent water pollution and to protect the beneficial uses of the waters of the state through required treatment of sewage and established water quality standards and to require permits by persons having a potential to discharge pollutants into the waters of the state.

2. K.S.A. 2-1915 empowers the State Conservation Commission to develop programs to assist the protection, conservation and management of soil and water resources in the state, including riparian areas.

3. K.S.A. 75-5657 empowers the State Conservation Commission to provide financial assistance for local project work plans developed to control nonpoint source pollution.

4. K.S.A. 82a-901, et seq. empowers the Kansas Water Office to develop a state water plan directing the protection and maintenance of surface water quality for the waters of the state.

5. K.S.A. 82a-951 creates the State Water Plan Fund to finance the implementation of the *Kansas Water Plan.*

6. K.S.A. 82a-701, et seq. authorizes the Chief Engineer of the Division of Water Resources to condition the appropriation and use of water so as to not cause degradation of the water quality of Kansas streams and lakes.

7. The *Kansas Water Plan* and the Solomon Basin Plan provide the guidance to state agencies to coordinate programs intent on protecting water quality and to target those programs to geographic areas of the state for high priority in implementation.

Funding: The State Water Plan Fund annually generates $16-18 million and is the primary funding mechanism for implementing water quality protection and pollutant reduction activities in the state through the *Kansas Water Plan*. The state water planning process, overseen by the Kansas Water Office, coordinates and directs programs and funding toward watersheds and water resources of highest priority. Typically, the state allocates at least 50% of the fund to programs supporting water quality protection. This watershed and its TMDL are a Low Priority consideration and should not receive funding, until evaluation of irrigation best management practices indicate potential salt load abatement.

Effectiveness: Minimal control can be exerted on the amount of natural background.

6. MONITORING

KDHE will continue to collect samples from Waconda Lake and at Stations 014, 542, 543, 544, 665, 666, 668, 669, 670, and 721. Based on that sampling, the priority status will be evaluated in 2007 including application of numeric criteria based on background concentrations. Should impaired status remain, the desired endpoints under this TMDL will be refined and direct more intensive sampling will need to be conducted under specified seasonal flow conditions over the period 2008-2012.

Monitoring of sulfate levels in effluent will be a condition of NPDES and state permits for facilities. This monitoring will continually assess the functionality of the systems in reducing sulfate levels in the effluent released to the streams upstream of Waconda Lake.

7. FEEDBACK

Public Meetings: Public meetings to discuss TMDLs in the Solomon Basin were held January 7 and March 3, 2003 in Stockton. An active Internet Web site was established at http://www.kdhe.state.ks.us/tmdl/ to convey information to the public on the general establishment of TMDLs and specific TMDLs for the Solomon Basin.

Public Hearing: A Public Hearing on the TMDLs of the Solomon Basin was held in Stockton on June 2, 2003.

Basin Advisory Committee: The Solomon Basin Advisory Committee met to discuss the TMDLs in the basin on October 3, 2002, January 7, March 3, and June 2, 2003.

Milestone Evaluation: In 2008, evaluation will be made as to the degree of implementation which has occurred within the watershed and current condition of Waconda Lake. Subsequent decisions will be made regarding the implementation approach and follow up of additional implementation in the watershed.

Consideration for 303(d) Delisting: The lake will be evaluated for delisting under Section 303(d), based on the monitoring data over the period 2008-2012. Therefore, the decision for delisting will come about in the preparation of the 2012 303(d) list. Should modifications be made to the applicable water quality criteria during the ten-year implementation period, consideration for delisting, desired endpoints of this TMDL and implementation activities may be adjusted accordingly.

Incorporation into Continuing Planning Process, Water Quality Management Plan and the Kansas Water Planning Process: Under the current version of the Continuing Planning Process, the next anticipated revision will come in 2004 which will emphasize revision of the Water Quality Management Plan. At that time, incorporation of this TMDL will be made into both documents. Recommendations of this TMDL will be considered in *Kansas Water Plan* implementation decisions under the State Water Planning Process after Fiscal Year 2008.

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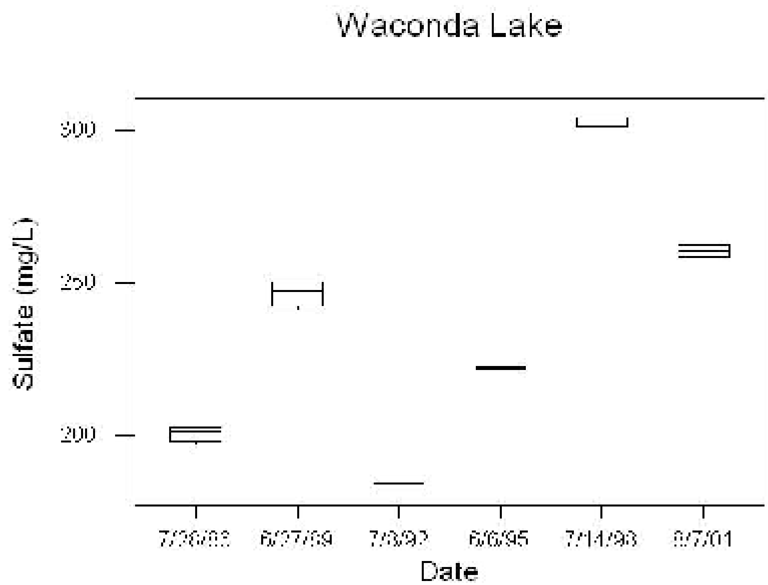
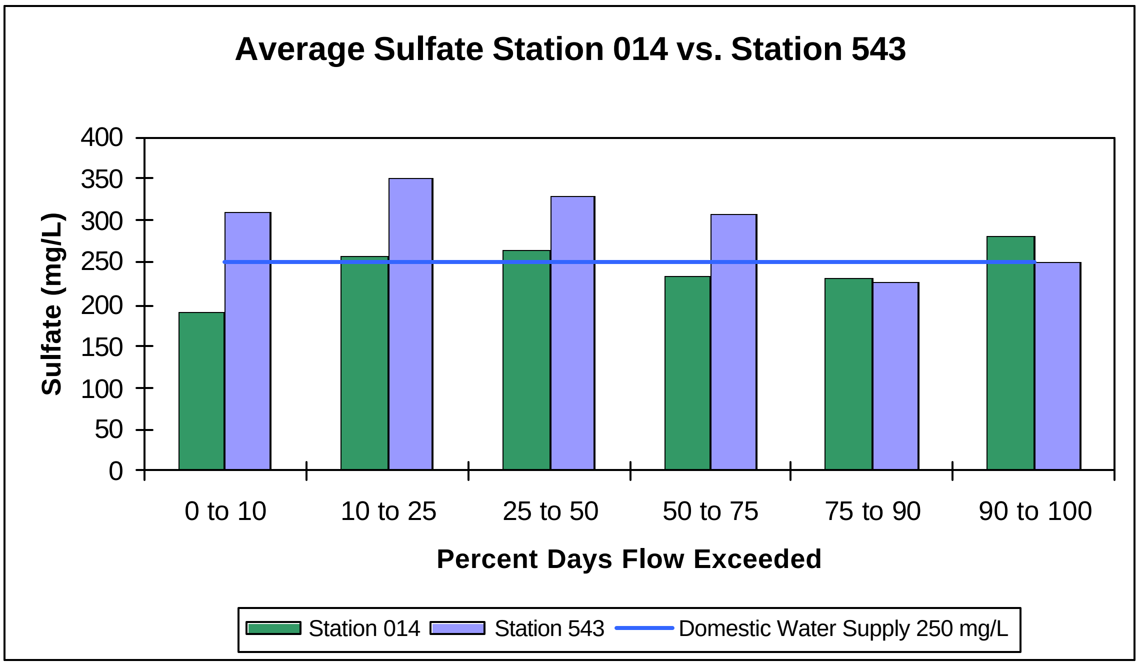
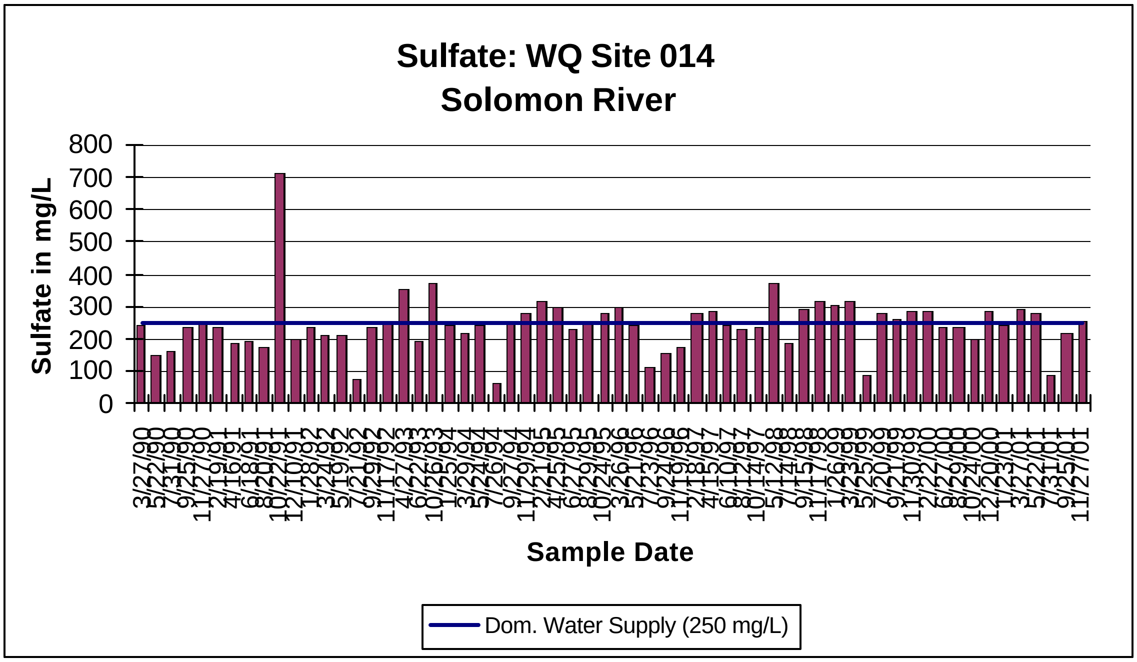
Liscek, Bonnie C. Methodology Used in Kansas Lake TMDLs [web page] Jul. 2001; http://www.kdhe.state.ks.us/tmdl/eutro.htm [Accessed 17 May 2002].

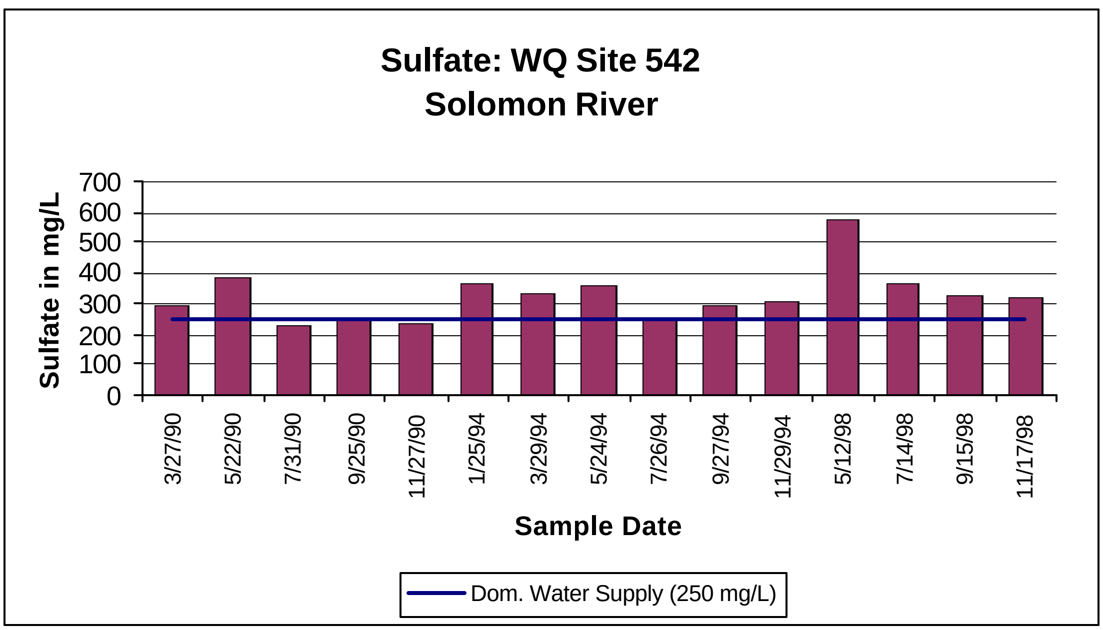
Whittemore, D. (18 Aug 2003). Salt source assessment and analysis for the sulfate TMDL for Waconda Lake .

Appendix A - Boxplot and Concentration Graphs






Sulfate: WQ Site 014
Solomon River
Sulfate in mg/L
800
700
600
500
400
300
200
100
0
Sample Date
Dom. Water Supply (250 mg/L)


Sulfate: WQ Site 542
Solomon River
Sulfate in mg/L
700
600
500
400
300
200
100
0
3/27/90
5/22/90
7/31/90
9/25/90
11/27/90
1/25/94
3/29/94
5/24/94
7/26/94
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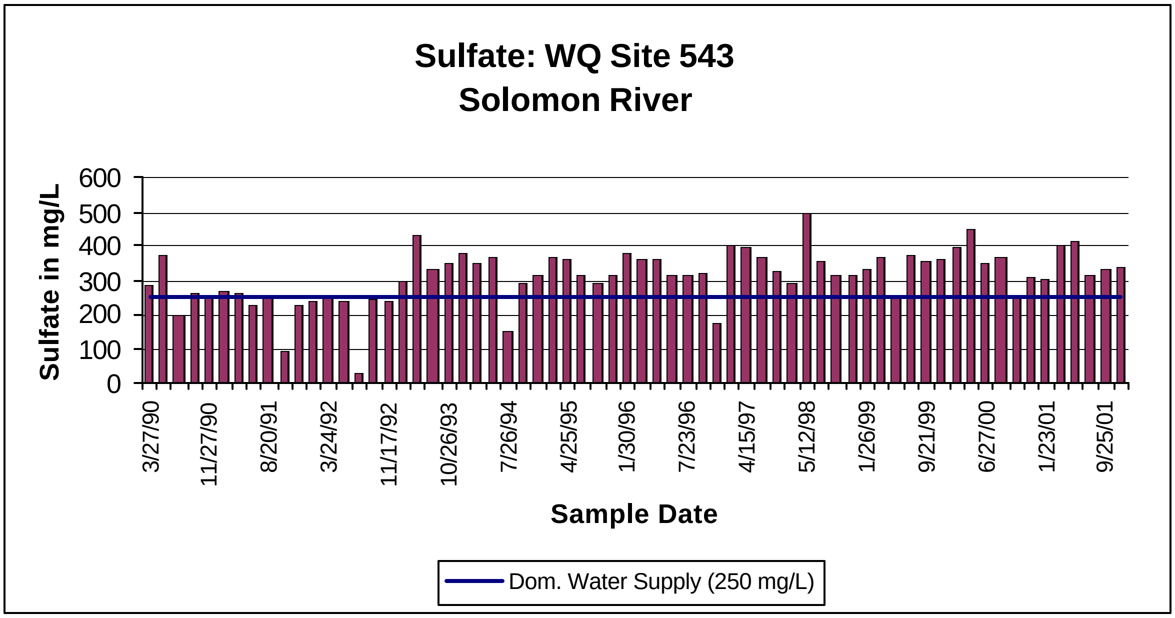
11/17/98
Sample Date
Dom. Water Supply (250 mg/L)



Sulfate: WQ Site 543
Solomon River
Sulfate in mg/L
600
500
400
300
200
100
0
3/27/90
11/27/90
8/20/91
3/24/92
11/17/92
10/26/93
7/26/94
4/25/95
1/30/96
7/23/96
4/15/97
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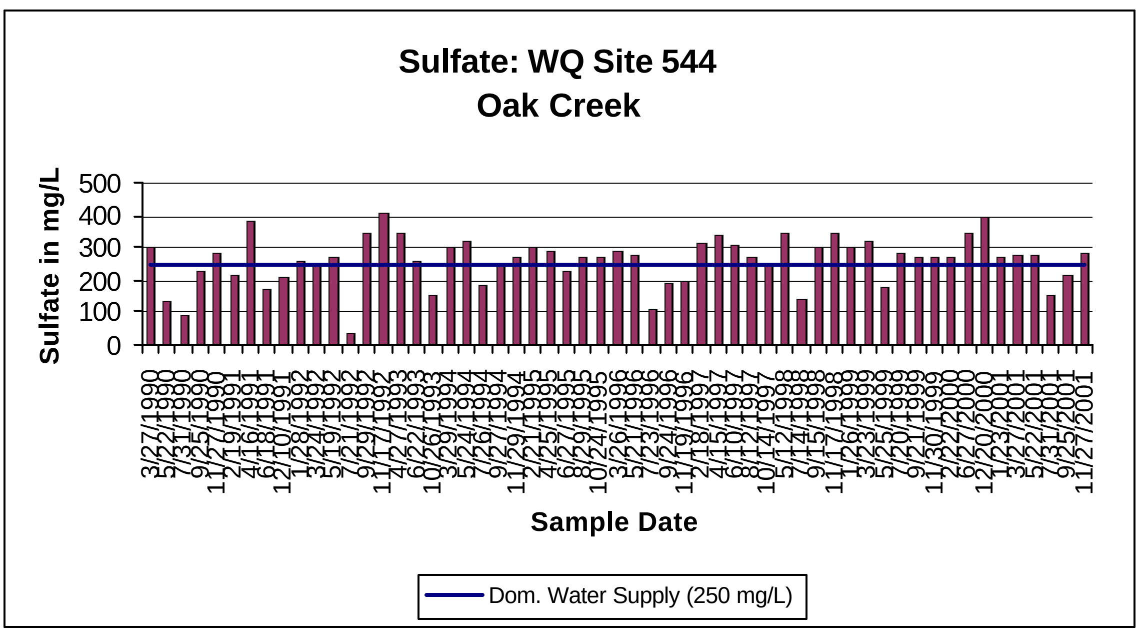
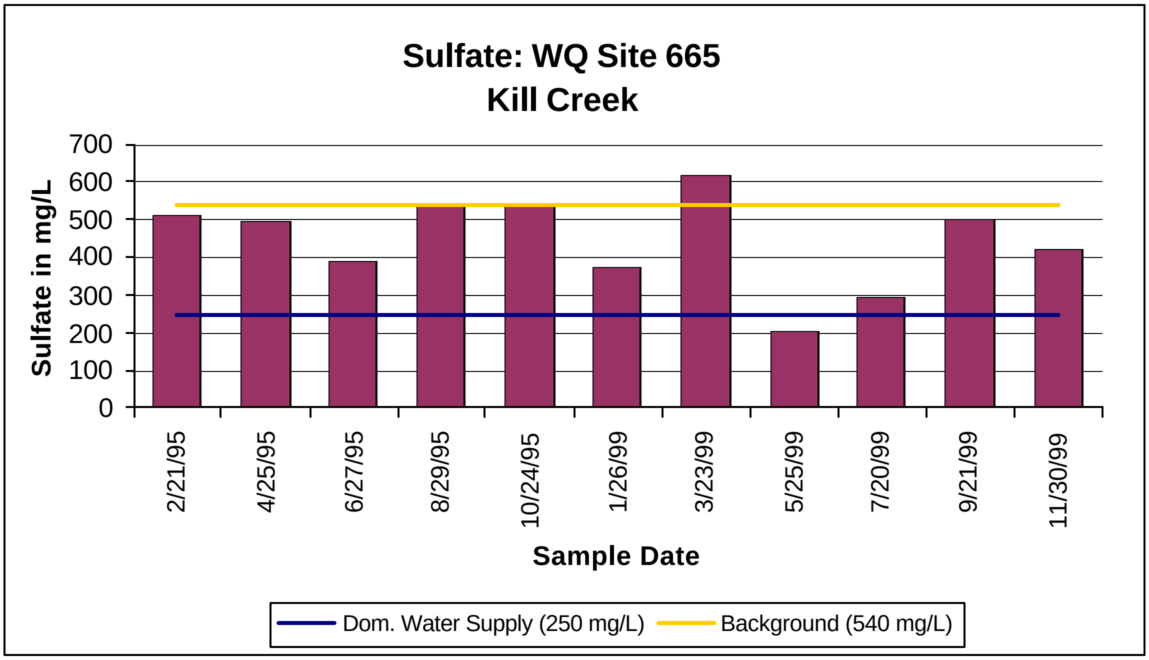
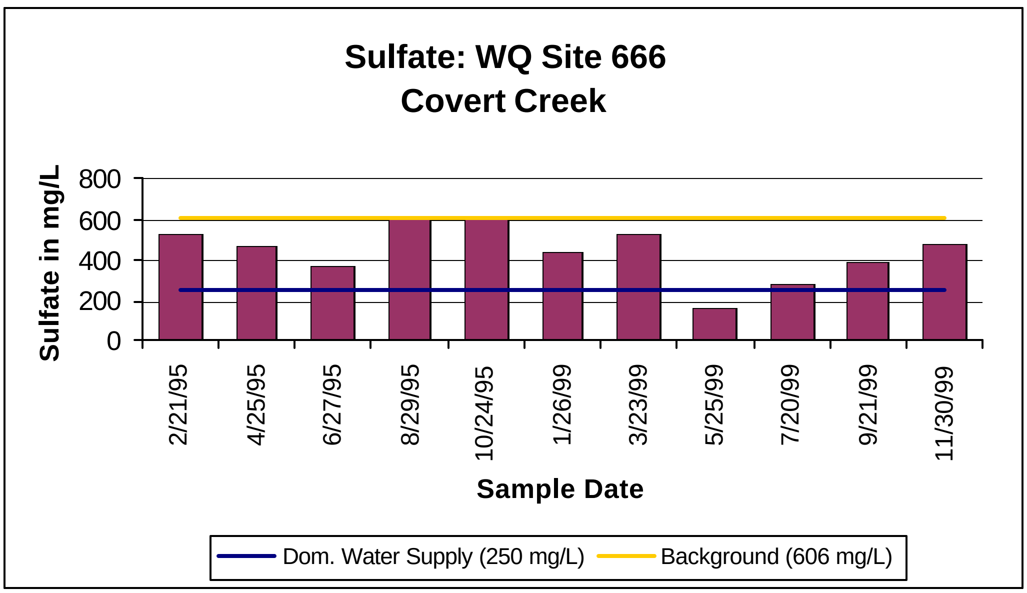
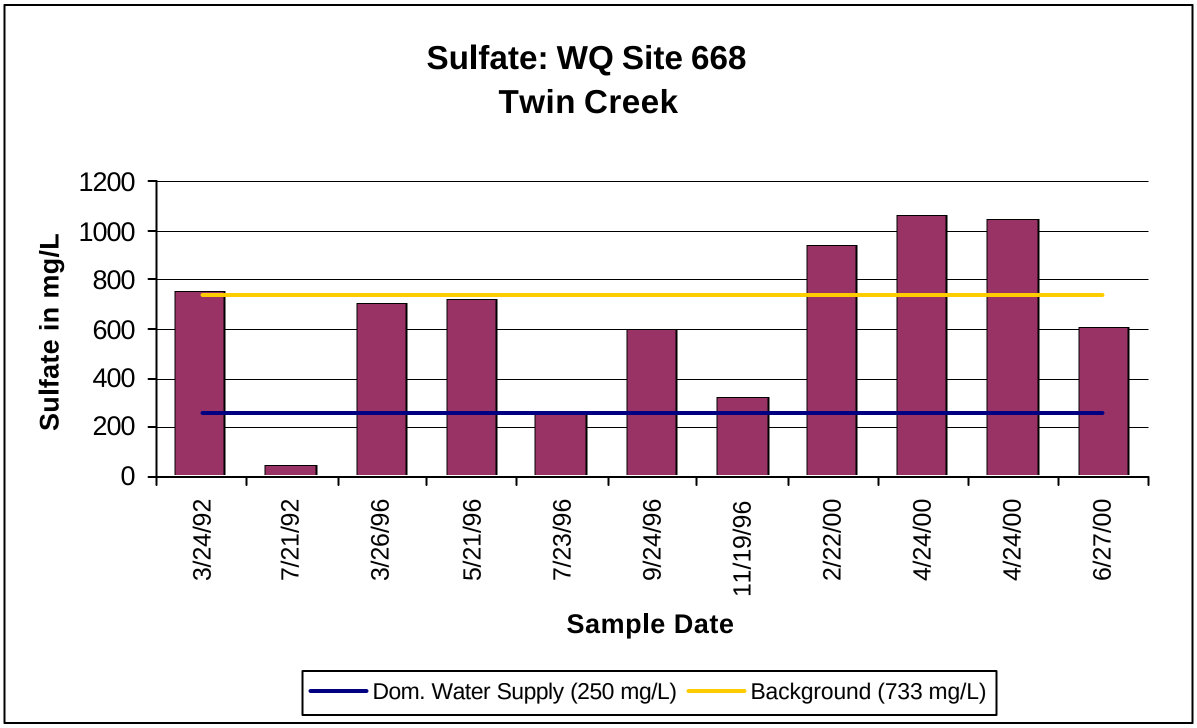
1/23/01
9/25/01
Sample Date
Dom. Water Supply (250 mg/L)



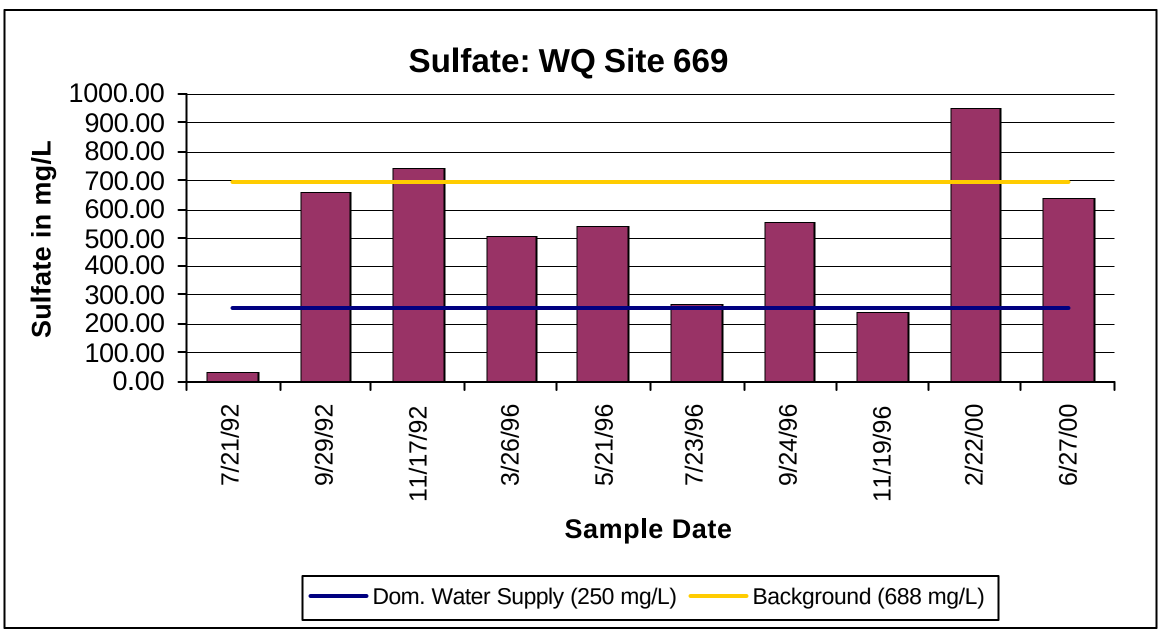
Sulfate: WQ Site 544
Oak Creek
Sulfate in mg/L
500
400
300
200
100
0
Sample Date
Dom. Water Supply (250 mg/L)


Sulfate: WQ Site 665
Kill Creek
Sulfate in mg/L
700
600
500
400
300
200
100
0
2/21/95
4/25/95
6/27/95
8/29/95
10/24/95
1/26/99
3/23/99
5/25/99
7/20/99
9/21/99
11/30/99
Sample Date
Dom. Water Supply (250 mg/L)
Background (540 mg/L)

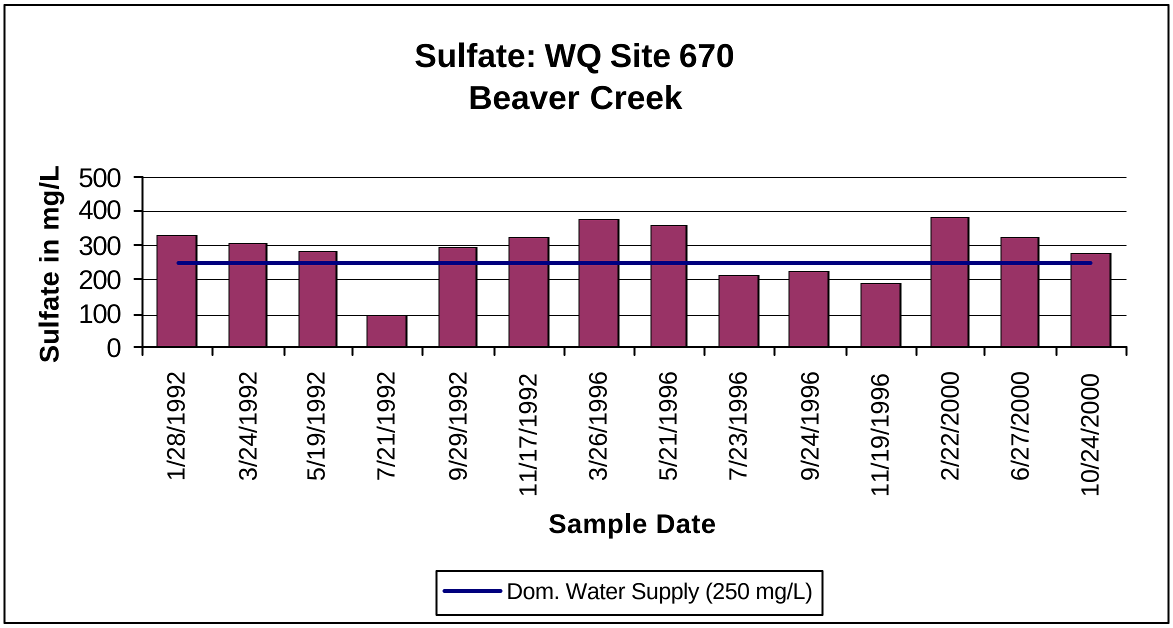

Sulfate: WQ Site 666
Covert Creek
Sulfate in mg/L
800
600
400
200
0
2/21/95
4/25/95
6/27/95
8/29/95
10/24/95
1/26/99
3/23/99
5/25/99
7/20/99
9/21/99
11/30/99
Sample Date
Dom. Water Supply (250 mg/L)
Background (606 mg/L)

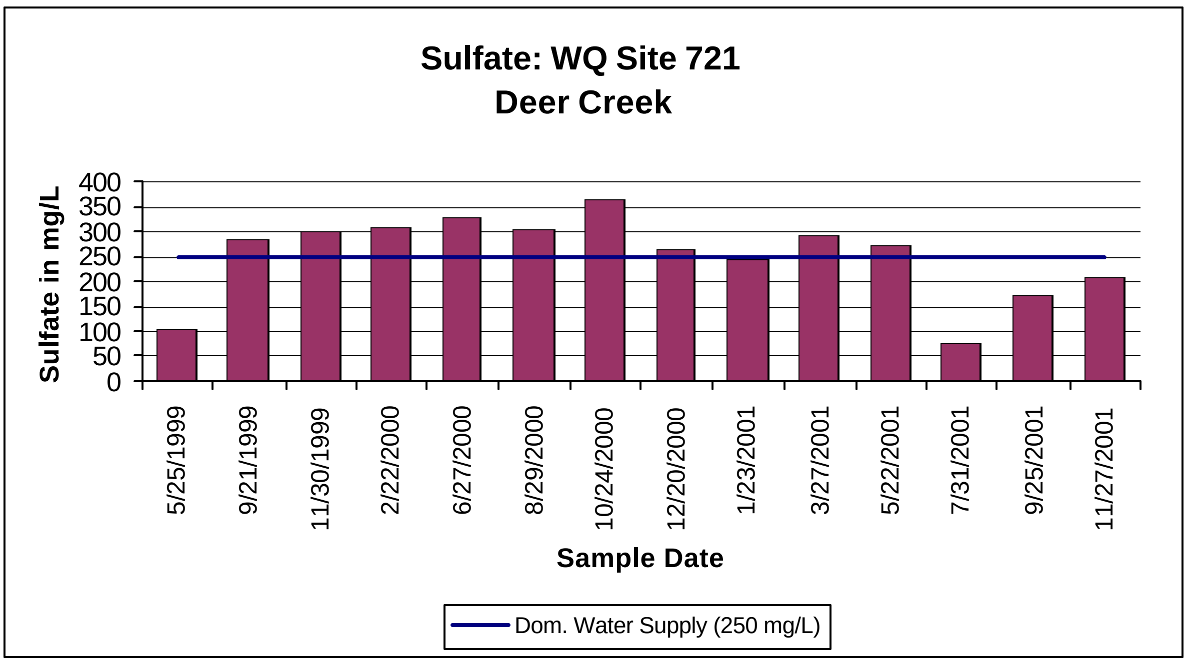


Sulfate: WQ Site 668
Twin Creek
Sulfate in mg/L
1200
1000
800
600
400
200
0
3/24/92
7/21/92
3/26/96
5/21/96
7/23/96
9/24/96
11/19/96
2/22/00
4/24/00
4/24/00
6/27/00
Sample Date
Dom. Water Supply (250 mg/L)
Background (733 mg/L)

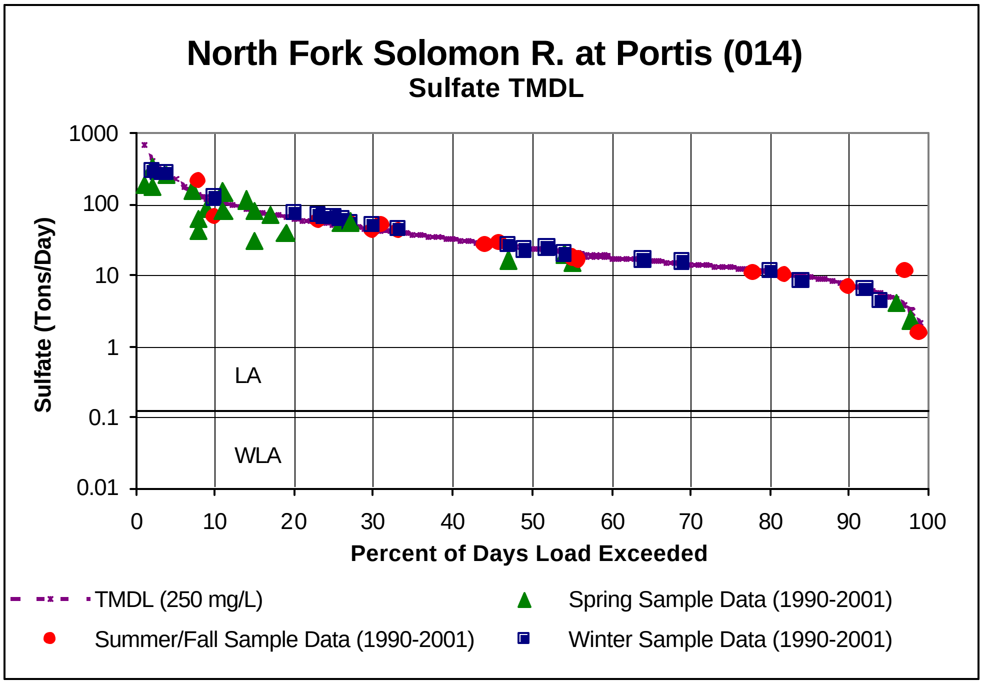


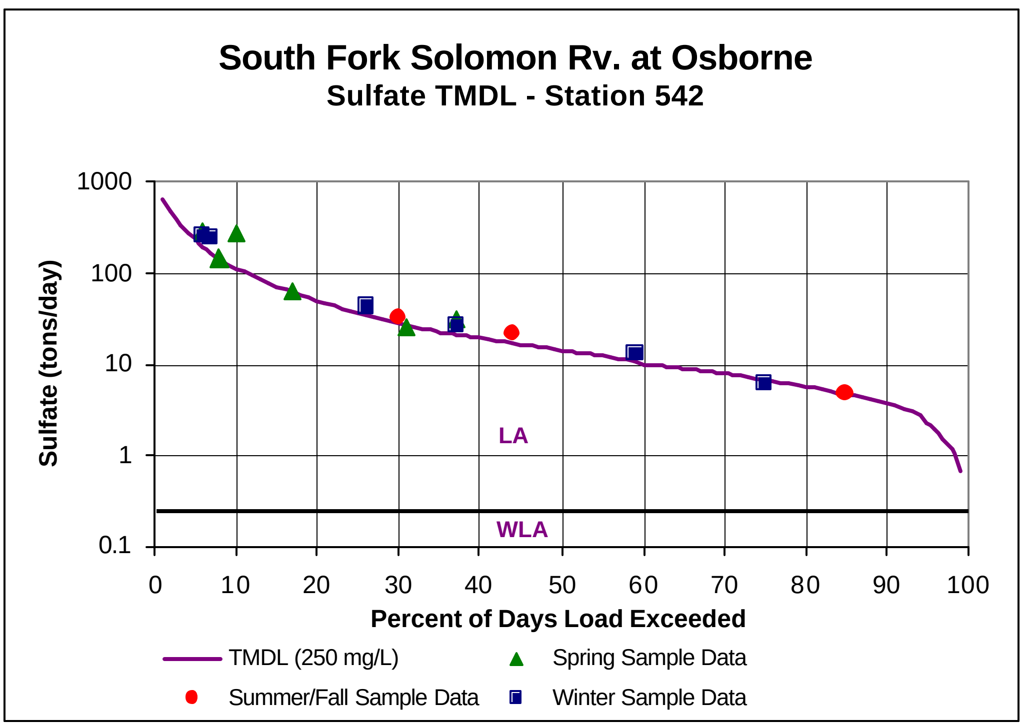
Sulfate: WQ Site 669
Sulfate in mg/L
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
7/21/92
9/29/92
11/17/92
3/26/96
5/21/96
7/23/96
9/24/96
11/19/96
2/22/00
6/27/00
Sample Date
Dom. Water Supply (250 mg/L)
Background (688 mg/L)

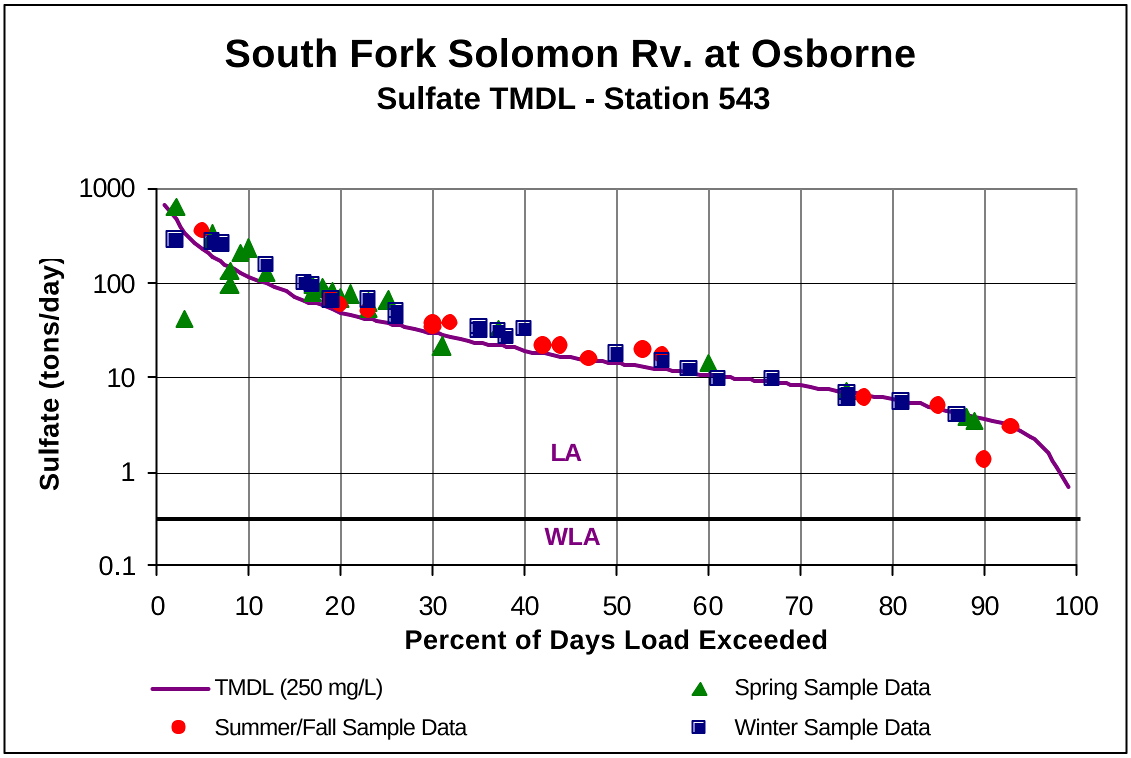

Sulfate: WQ Site 670
Beaver Creek
Sulfate in mg/L
500
400
300
200
100
0
1/28/1992
3/24/1992
5/19/1992
7/21/1992
9/29/1992
11/17/1992
3/26/1996
5/21/1996
7/23/1996
9/24/1996
11/19/1996
2/22/2000
6/27/2000
10/24/2000
Sample Date
Dom. Water Supply (250 mg/L)

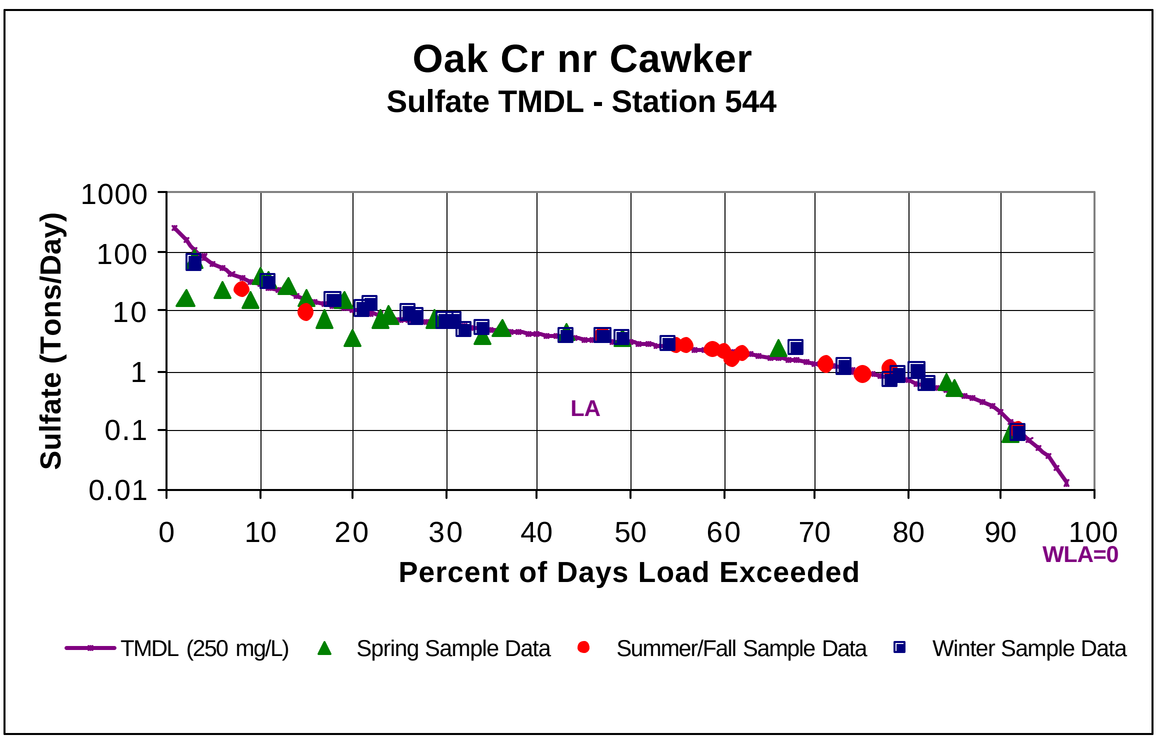

Sulfate: WQ Site 721
Deer Creek
Sulfate in mg/L
400
350
300
250
200
150
100
50
0
5/25/1999
9/21/1999
11/30/1999
2/22/2000
6/27/2000
8/29/2000
10/24/2000
12/20/2000
1/23/2001
3/27/2001
5/22/2001
7/31/2001
9/25/2001
11/27/2001
Sample Date
Dom. Water Supply (250 mg/L)

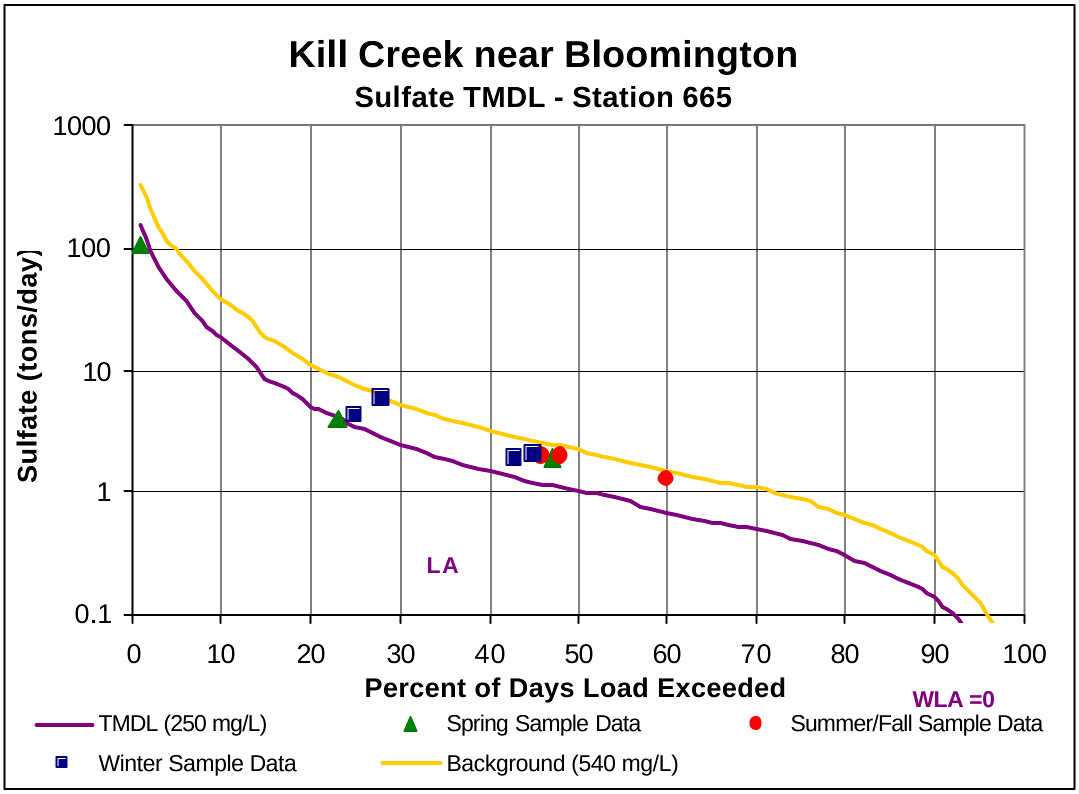
Appendix B - Load Duration Curves



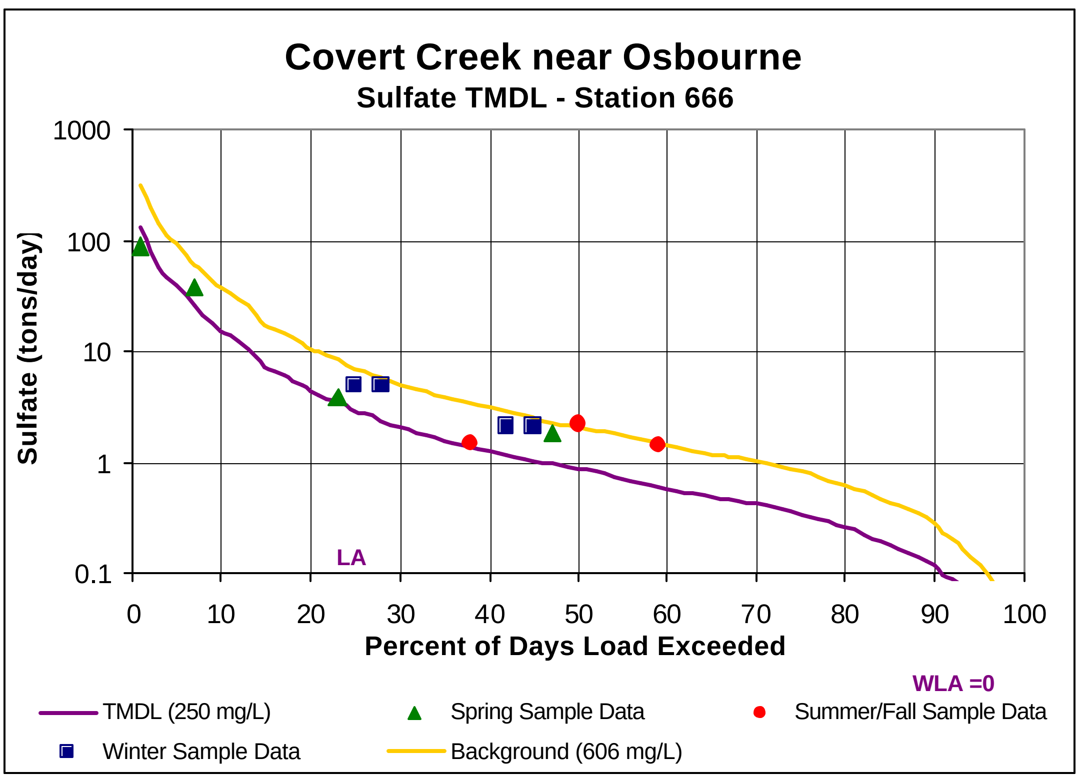



South Fork Solomon Rv. at Osborne
Sulfate TMDL - Station 543
Sulfate (tons/day)
1000
100
10
1
0.1
0
10
20
30
40
50
60
70
80
90
100
Percent of Days Load Exceeded
LA
WLA
TMDL (250 mg/L)
Spring Sample Data
Summer/Fall Sample Data
Winter Sample Data

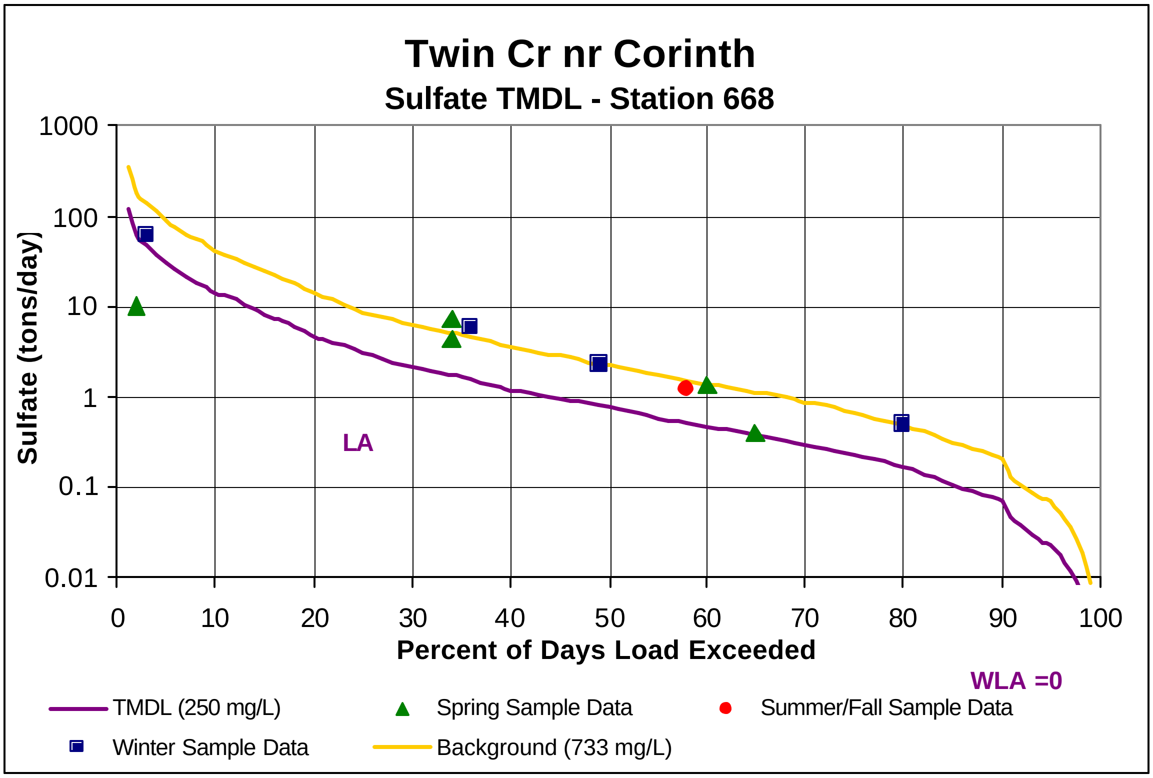

Oak Cr nr Cawker
Sulfate TMDL - Station 544
Sulfate (Tons/Day)
1000
100
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
100
Percent of Days Load Exceeded
LA
WLA=0
TMDL (250 mg/L)
Spring Sample Data
Summer/Fall Sample Data
Winter Sample Data

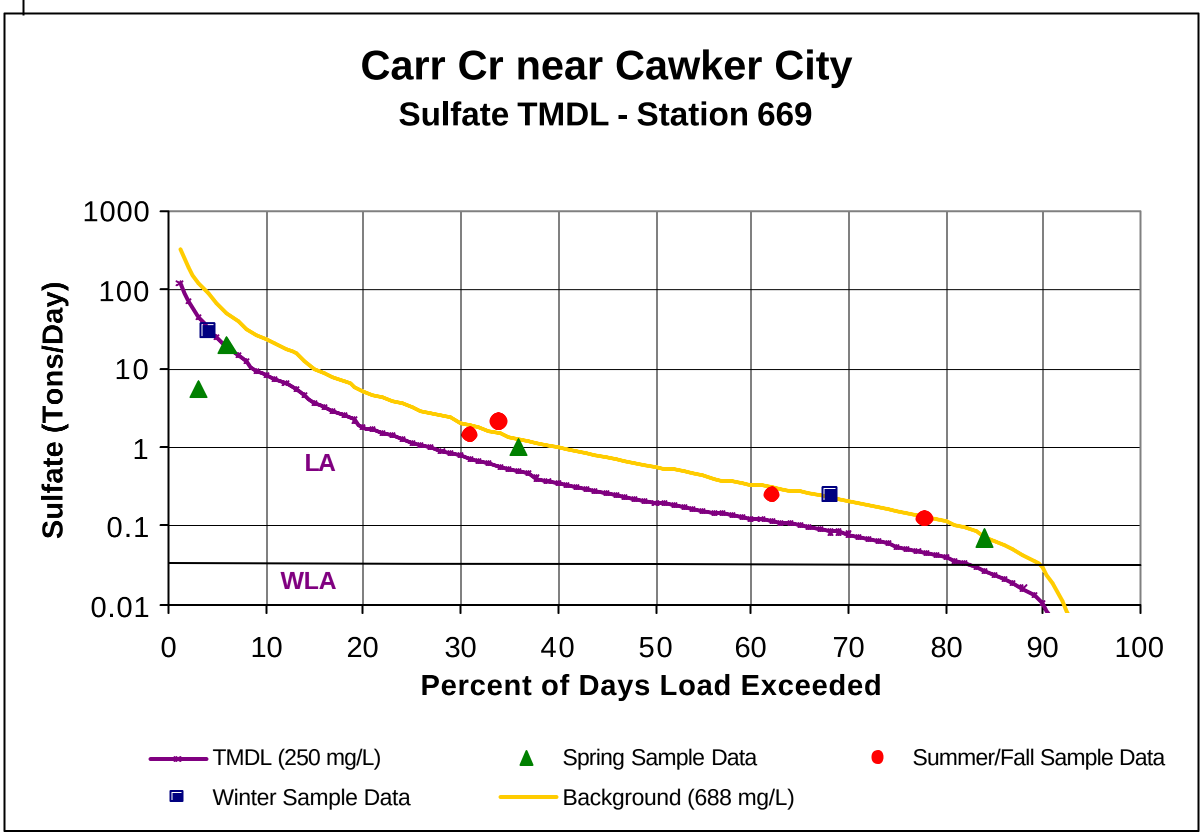


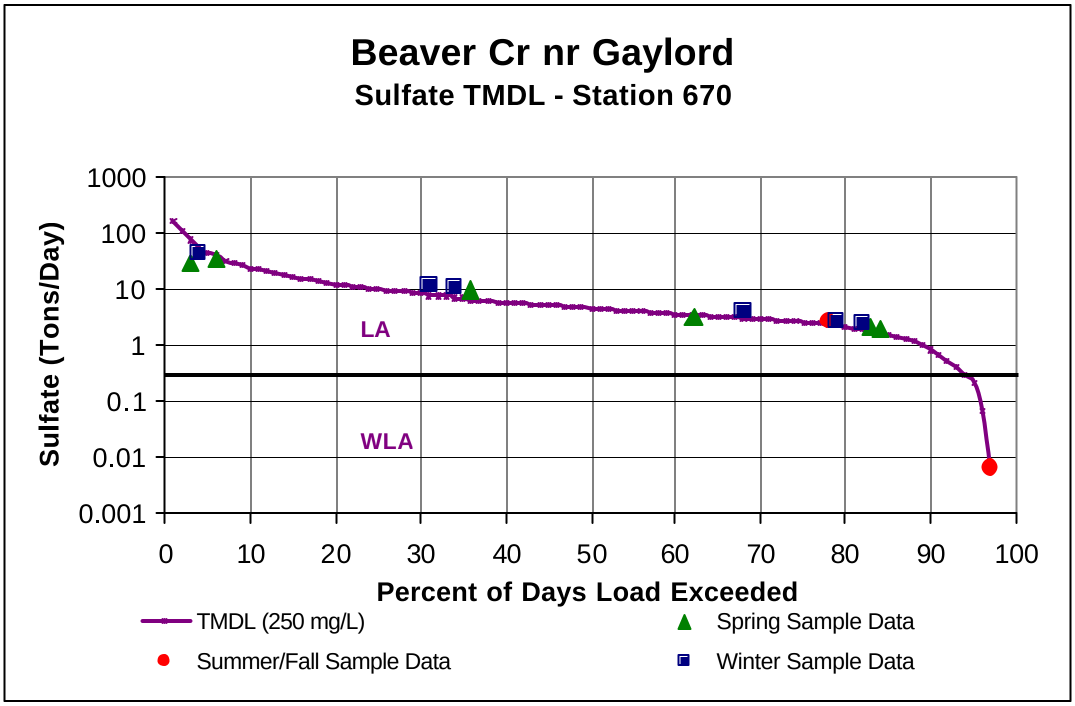
Kill Creek near Bloomington
Sulfate TMDL - Station 665
Sulfate (tons/day)
1000
100
10
1
0.1
0
10
20
30
40
50
60
70
80
90
100
LA
Percent of Days Load Exceeded
WLA =0
TMDL (250 mg/L)
Spring Sample Data
Summer/Fall Sample Data
Winter Sample Data
Background (540 mg/L)

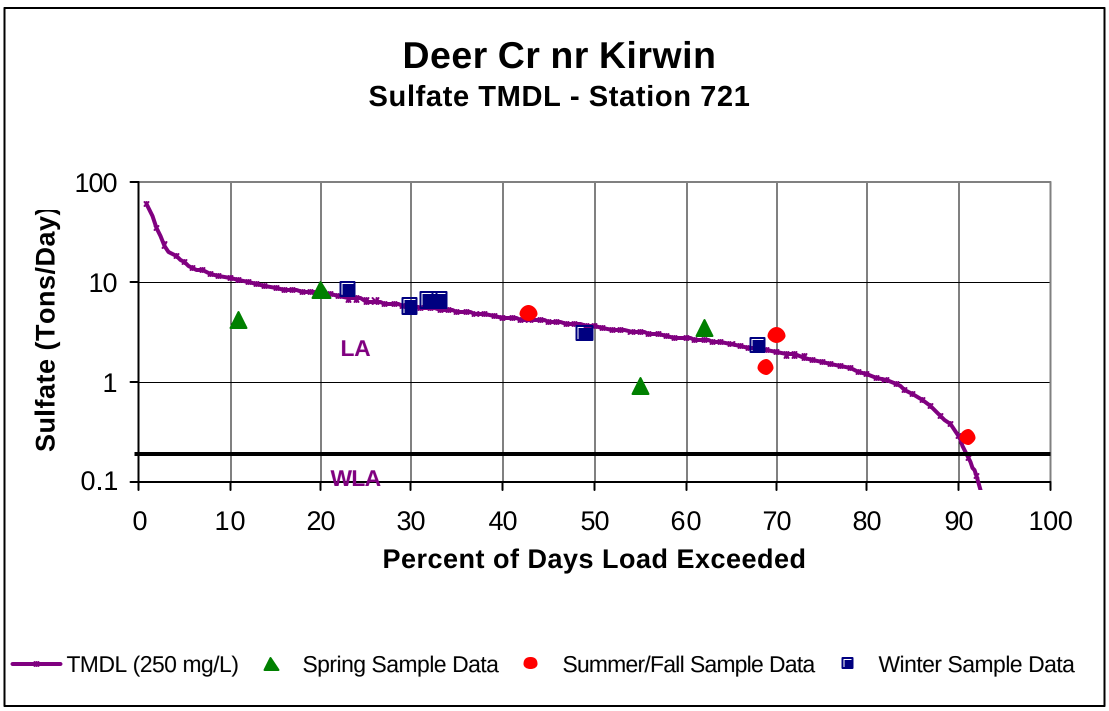


Covert Creek near Osbourne
Sulfate TMDL - Station 666
Sulfate (tons/day)
1000
100
10
1
0.1
0
10
20
30
40
50
60
70
80
90
100
LA
Percent of Days Load Exceeded
WLA =0
TMDL (250 mg/L)
Spring Sample Data
Summer/Fall Sample Data
Winter Sample Data
Background (606 mg/L)


Twin Cr nr Corinth
Sulfate TMDL - Station 668
Sulfate (tons/day)
1000
100
10
1
0.1
0.01
LA
0
10
20
30
40
50
60
70
80
90
100
Percent of Days Load Exceeded
WLA =0
TMDL (250 mg/L)
Spring Sample Data
Summer/Fall Sample Data
Winter Sample Data
Background (733 mg/L)


Carr Cr near Cawker City
Sulfate TMDL - Station 669
Sulfate (Tons/Day)
1000
100
10
1
0.1
0.01
LA
WLA
0
10
20
30
40
50
60
70
80
90
100
Percent of Days Load Exceeded
TMDL (250 mg/L)
Spring Sample Data
Summer/Fall Sample Data
Winter Sample Data
Background (688 mg/L)


Beaver Cr nr Gaylord
Sulfate TMDL - Station 670
Sulfate (Tons/Day)
1000
100
10
1
0.1
0.01
0.001
LA
WLA
0
10
20
30
40
50
60
70
80
90
100
Percent of Days Load Exceeded
TMDL (250 mg/L)
Spring Sample Data
Summer/Fall Sample Data
Winter Sample Data


Deer Cr nr Kirwin
Sulfate TMDL - Station 721
Sulfate (Tons/Day)
100
10
1
0.1
LA
WLA
0
10
20
30
40
50
60
70
80
90
100
Percent of Days Load Exceeded
TMDL (250 mg/L)
Spring Sample Data
Summer/Fall Sample Data
Winter Sample Data

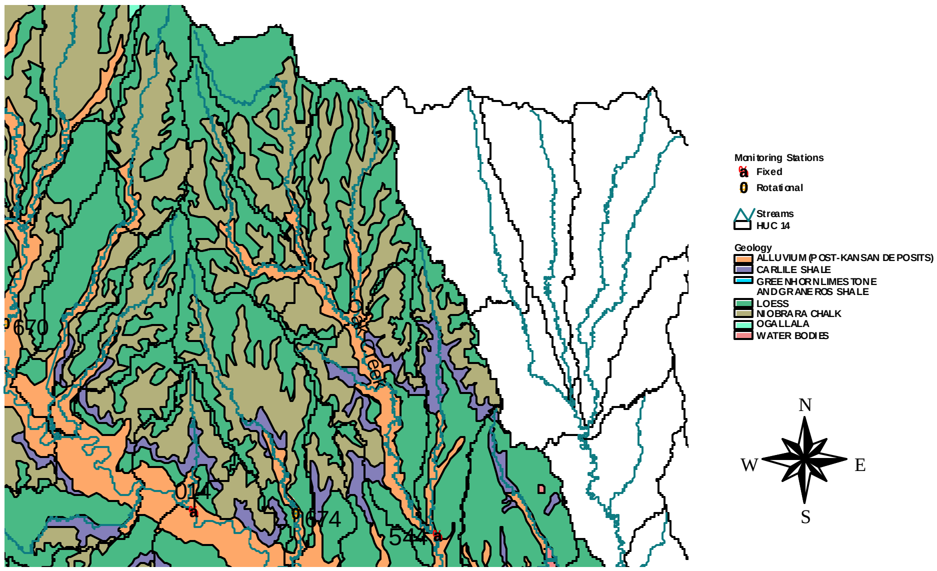
Appendix C - Wasteload Allocation

Station	Kansas Permit Number	Facility Name	Type	Design Flow (MGD)	SO4 influent (mg/L)	SO4 Effluent (mg/L)	SO4 Load (tons/day)	Water Quality Standard (mg/L)
14	M-SO21-OO02	KENSINGTON	Three-cell lagoon	0.055	332.07	332.07	0.076	250
542	M-SO41-OO01	STOCKTON MWTP	Activated Sludge	0.275	353.76	353.76	0.406	250
543	M-SO29-OO02	OSBORNE WWTP	Four-cell Lagoon	0.286	281.45	281.45	0.336	250
669	M-SO42-OO01	TIPTON WWTF	Three-cell lagoon	0.023	293.33	293.33	0.028	690
670	M-SO38-IO01	SMITH CENTER MWTP	Activated Sludge	0.500	249.92	249.92	0.522	250
721	M-SO31-OO01	PHILLIPSBURG MWTP	Activated Sludge In construction	0.350	271.51	271.51	0.397	250
721	I-SO31-PO01	TAMKO ROOFING PRODUCTS,INC.	aerated cells	0.027		250*	0.028	250
Waconda Lake Inflow	M-SO12-OO01	DOWNS MWWTP	Trickling Filter	0.150	41.94	41.94	0.026	250
Waconda Lake Inflow	F-SO08-OO01	CAWKER CITY - WACONDA RES.	Three-cell lagoon	0.085	240.98	240.98	0.086	250
			Total	**1.751**			**1.905**	

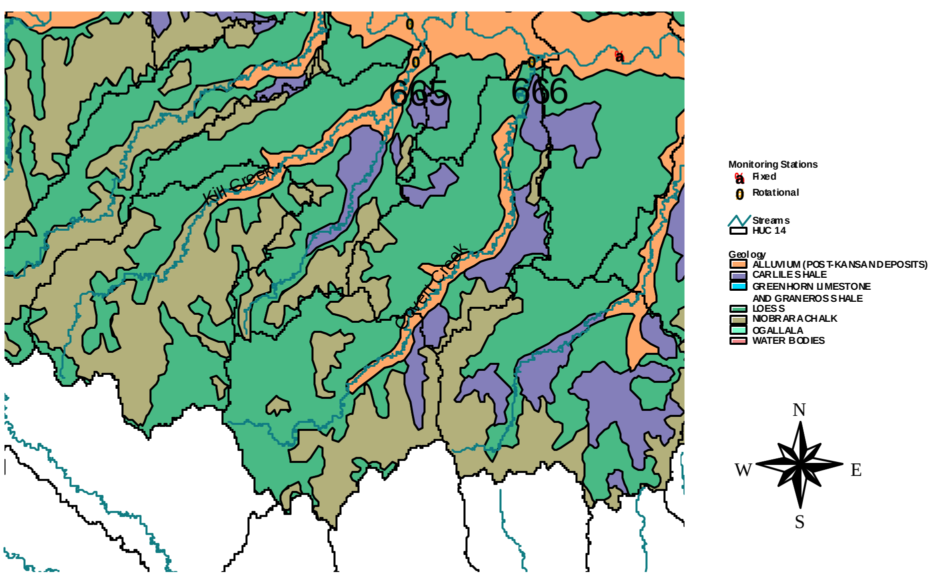
* Concentration designated in permit

Appendix D - Geology Maps for Each Tributary

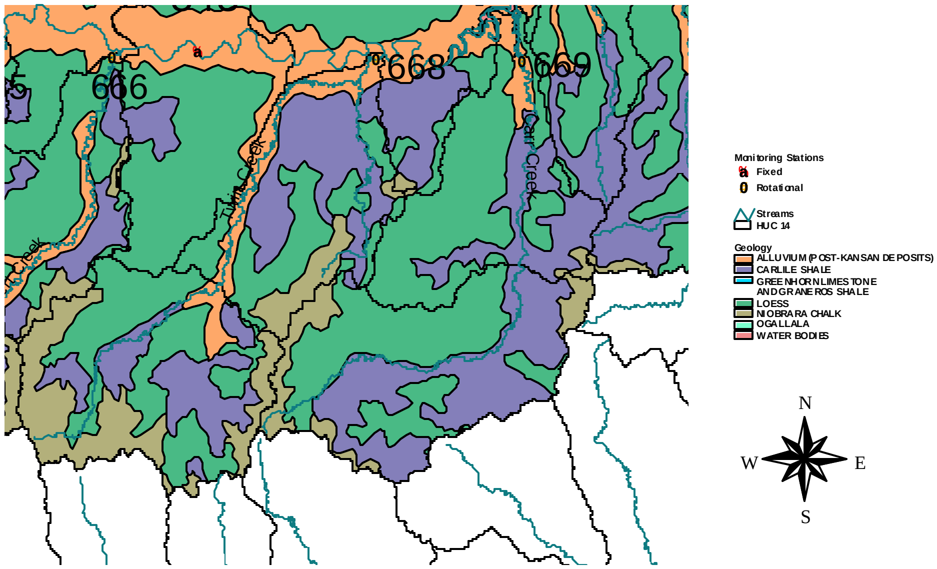
Station 544 near Cawker City (Oak Creek)



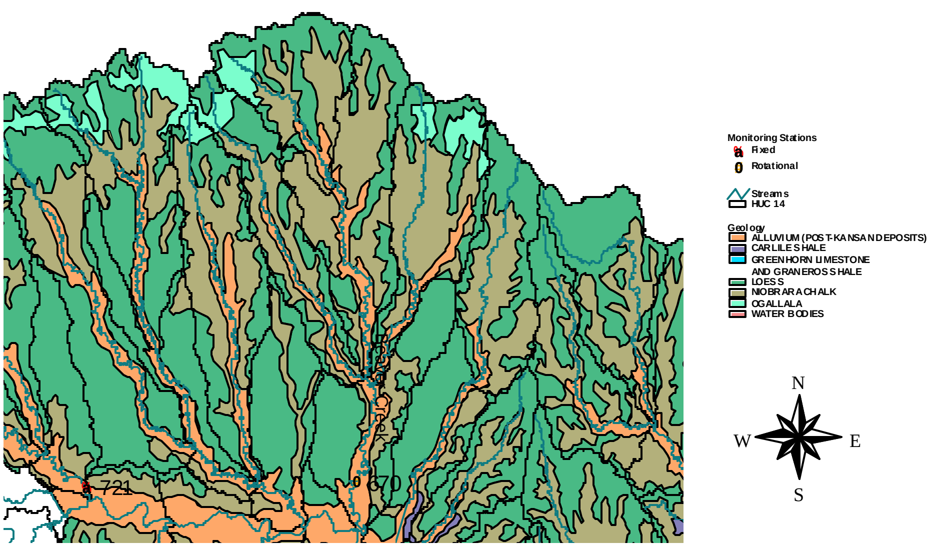
Station 665 near Bloomington (Kill Creek) and Station 666 near Osborne (Covert Creek)



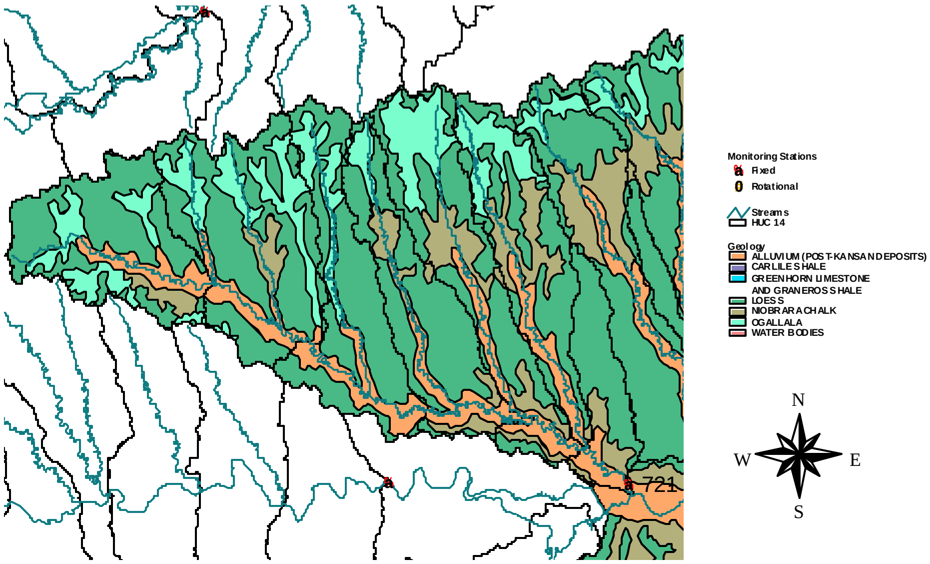
Station 668 near Corinth (Twin Creek) and Station 669 near Cawker City (Carr Creek)



Station 670 near Gaylord (Beaver Creek)



Station 721 near Kirwin (Deer Creek)



Approved January 21, 2004